

STUDIES ON WATER MOVEMENTS AND SEDIMENTS IN
SOUTHERN LAKE MICHIGAN

Part I. Water-Volume Transports Across the Mid-
lake Sill, and Current Structure Over the Sill

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PREFACE TO THE ENTIRE REPORT

Several factors have dictated that this final report should be in separate parts.

The contract covered studies of different sorts. By the nature of the studies, the times required for work-up and analysis of data have varied widely, some parts being completed long before others could be finished. The different studies have required greatly varying amounts of ship-time and some, which required unexpectedly large amounts of ship-time, are being augmented by data obtained during cruises for other projects when vessels are in suitable regions. Finally, it is believed that assimilation by the reader is aided by brevity and unit reporting.

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INTRODUCTION

Lake Michigan is divided into northern and southern basins by an area of elevated and irregular bottom that lies in the region between Milwaukee, Wisconsin, and Muskegon, Michigan. While this elevated area is not a complete sill, being cut through by deep water near the Michigan shore and just off Milwaukee, it has sufficiently sill-like characteristics to raise questions as to the effect it may exert on the flushing out of the southern basin.

This study was undertaken to ascertain whether significant volumes of water were being exchanged between the northern and southern basins across the sill. If volume-transport across the sill exists, its magnitude (plus that of river inflows) in comparison to the volume of water in the southern basin should give a clue as to whether the southern basin is well or poorly flushed.

Details about the physical structure of water currents over the sill were not expected, but have come to light.

METHODS

The basic method of the study was the determination of current direction, current velocity, and water volume transport by the dynamic height method of Ayers (1956) and Ayers and Bachman (1957).

Bathythermograph lowerings at about two-mile intervals (ca 2.5 miles on 10 August 1962) were made underway on courses parallel to the sill and, in all but one case, over the sill.

Navigation was by radar bearing and range out to about 20 miles from the shore being departed, by dead-reckoning in mid-lake, and again by radar from about 20 miles off the shore being approached.

The first BT sounding was in each case from 1/2 mile to 2.5 miles from the shore being departed and the last at two miles, more or less, from the shore being approached.

Vertical temperature profiles were read from the bathythermograph trace, in effect reducing the trace to a series of straight-line segments of various lengths.

Corrected depth and temperature data were fed to an IBM 7090 computer which was programed to make all the necessary computations.

As a check, the section from Racine, Wisconsin, to Grand Haven, Michigan, 9 November 1962 was calculated by hand. Agreement between hand calculation and computer calculation was satisfactory.

Current direction (component normal to ship's course), and velocity were obtained at each 10 decibar level from 0 to 60.

A reference level at 60 decibars was chosen as giving a minimum interference from the bottom.

At the ends of each section, where the bottom was at less than 60 meters, substitution was made from the lower part of the nearest full-depth station according to the method of Helland-Hansen (1934).

Lake Michigan winds at each of the synoptic hours were obtained either 1) from microfilmed copies of ships' weather logs obtained from the National Weather Records Center in Asheville, North Carolina, or 2) from teletype reports transmitted by selected Weather Bureau stations near the lake and received at the station at Willow Run Airport.

Mean ships' winds for each sector (west and east, using the 87th meridian as the dividing line) were obtained and entered as the wind for that sector, whenever ships' observations were available. On some occasions ship observations along the 87th meridian were used as the winds of both sectors.

At times when no ships' observations were available, Weather Bureau observations on land were utilized in the following manner:

In the west sector, the vector mean wind of the following stations was used: Milwaukee (MKE), Glenview, Illinois, (NBU), Joliet (JOT), Midway Airport, Chicago (MDW), O'Hare International Airport, Chicago (ORD), and Meigs Field, Chicago (CGX).

In the east sector, the vector mean wind of the following stations was used: Grand Rapids (GRR), Kalamazoo (AZO), Muskegon (MKG), and South Bend (SBN).

RESULTS

Eight transects have been obtained and analysed. In chronological order they are:

10 August 1962; Muskegon to Milwaukee

20 August 1962; Grand Haven to Milwaukee

3 November 1962; Grand Haven to Milwaukee

9 November 1962; Racine to Grand Haven

17 April 1963; Milwaukee to Grand Haven

20 May 1963; Grand Haven to Milwaukee

24 June 1963; Grand Haven to Port Washington

24 July 1963; Muskegon to Milwaukee

The bathythermograph data of these transects are given in the Appendix.

Tables 1 through 24 present the wind regimens of the days of the transects and of the preceding days; also presented in these tables are the gross volume transports of water across the transects, as well as the net volume transports and the indicated currents involved in the volume transports.

Volume Transports

Tables 2, 5, 8, 11, 14, 17, 20, and 23 present the gross and net water volume transports of the eight transects. These volumes were computed in terms of cubic meters per second of water moving through each of the 2-mile-by-60-meter blocks (2.5-mile-by-60-meter on 10 August 1962) composing the transect.

Summation of the individual transects gave net volume transport for each transect. Net transports obtained were as

follows:

10 VIII 62		47,280 m ³ /sec South
20 VIII 62	44,090 m ³ /sec North	
3 XI 62	7,075	
9 XI 62	34,285	
17 IV 63		5,016
20 V 63	5,981	
24 VI 63		3,883
24 VII 63	5,927	
	<hr/> 97,358 North	<hr/> 56,179 South
Grand Net: 41,179 m ³ /sec North		

Indicated Structure of Currents

Tables 3, 6, 9, 12, 15, 18, 21, and 24 present the indicated currents involved in the water transports. These indicated currents were obtained by dividing the net volume transport of each 2-mile-by-10-meter block (2.5-mile-by-10 meter on 10 August 1962) in the 60-meter-deep transect by the area of each 10-meter-deep block.

The original purpose of this step was to provide an approximation of the velocities and directions of 2-to-5-day-average relative currents that might be compared to 2-to-5-day-average currents recorded by the USPH metered buoys installed along the Muskegon to Milwaukee line.

To actually make this comparison is beyond the scope of the contract, and will not be possible until the current data from appropriate levels in the metered buoy systems are read out. The tables give the possibility of making the comparison if it

should be desired.

The indicated currents varied from zero to tens of centimeters per second. In general the greatest indicated currents occurred in the surface layer and along either the east or west shore of the lake.

In general, the velocities of the indicated currents decreased toward the bottom and in the central portion of the lake.

Streaked Nature of the Indicated Currents

Quite unexpected was the fact that the indicated currents were arranged in alternate streaks of northward and southward current.

The widths of the alternating current streaks varied, apparently in response to the wind regimen. The locations of the streaks also appeared to vary under different winds.

The streaks of current in most cases reached to the 60-meter level, although there were some instances where they did not.

The indicated structure of the currents is similar to the horizontal current-countercurrent arrangement suggested by Fuglister (1951, 1955) for the Gulf Stream, and confirmed by von Arx, Bumpus, and Richardson (1955). Fuglister's initial presentation of this current arrangement is shown in Figure 1.

The alternation of northward and southward current bands shows clearly in the underlined (north) and not underlined (south) indicated currents of Tables 3, 6, 9, 12, 15, 18, 21, and 24.

As a direct test of the reality of the bands or streaks of

indicated current, ten current drogues were set in a line past USPHS buoy #20 off Muskegon, Michigan, on 29 October 1963. The series of drogues began at the U. S. Weather Bureau-U. S. Public Health Service-University of Michigan weather tower one mile off the beach, continued at 2-mile intervals along a course to the south of west, passed about three-quarters of a mile north of USPHS buoy #20, and ended about six miles west of buoy #20.

These drogues were set in the period between 0911 and 1050 EDT under north wind which continued until after the period of drogue runs. The drogue movements that took place in 3-3/4 to 5 hours are shown in Figure 2.

All of the drogues, except the one immediately east of buoy #20, moved southward. Drogue #8, immediately east of the buoy, moved northward, almost directly upwind.

All the drogues were set to be influenced by the upper five feet of the water (surface drogues).

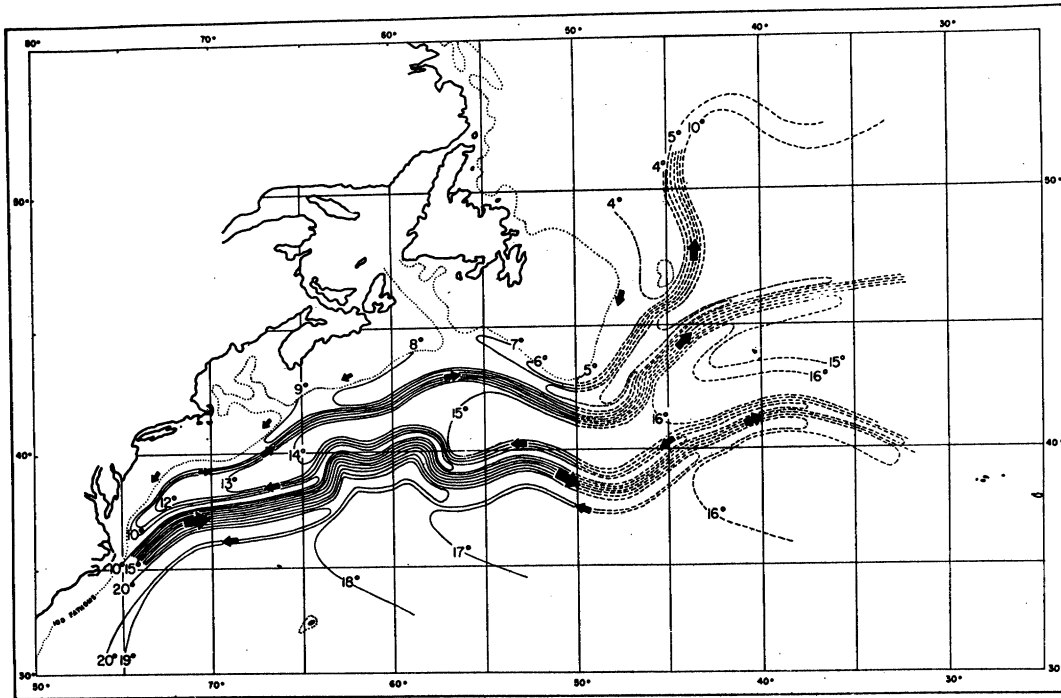


Fig. 1. Schematic chart of temperatures (°C.) at a depth of 200 meters in the Gulf Stream Area.

DISCUSSION

Drogue Sets of 29 October

Care must be taken to use this drogue study for no more than it is valid for. To command this number of drogues it was necessary to use some drogue floats that were known to be somewhat effected by wind. These were the floats of drogues 1 through 5. To contribute toward an assessment of the effect of windage on these floats, they were set alternately with low-riding low-windage floats (numbers 6 through 10).

Drogues 3 and 4 moved southward 0.75 and 0.4 miles in 4 hrs 22 min and 4 hrs 33 min, all respectively. At the time of writing the author is inclined to attribute the 0.4 mile movement of drogue 4 entirely to windage on its float. Perhaps read-out of the data from the 30-foot current meter of buoy #20 for the period 1017 through 1450 will enable a better assessment of the movement of drogue 4.

Drogue 8 was carried by a low-windage float, and cannot be denied.

Drogues 6, 7, 8, 9, and 10 were all carried by low-windage floats. They tell the essential story of the results, while drogues 1 through 5 augment the story with detail containing an incompletely-assessed windage error.

Current velocities indicted by the low-windage drogues were:

#6	0.4 mph southward
#7	0.4 mph southward
#8	0.07 mph northward
#9	0.13 mph southward

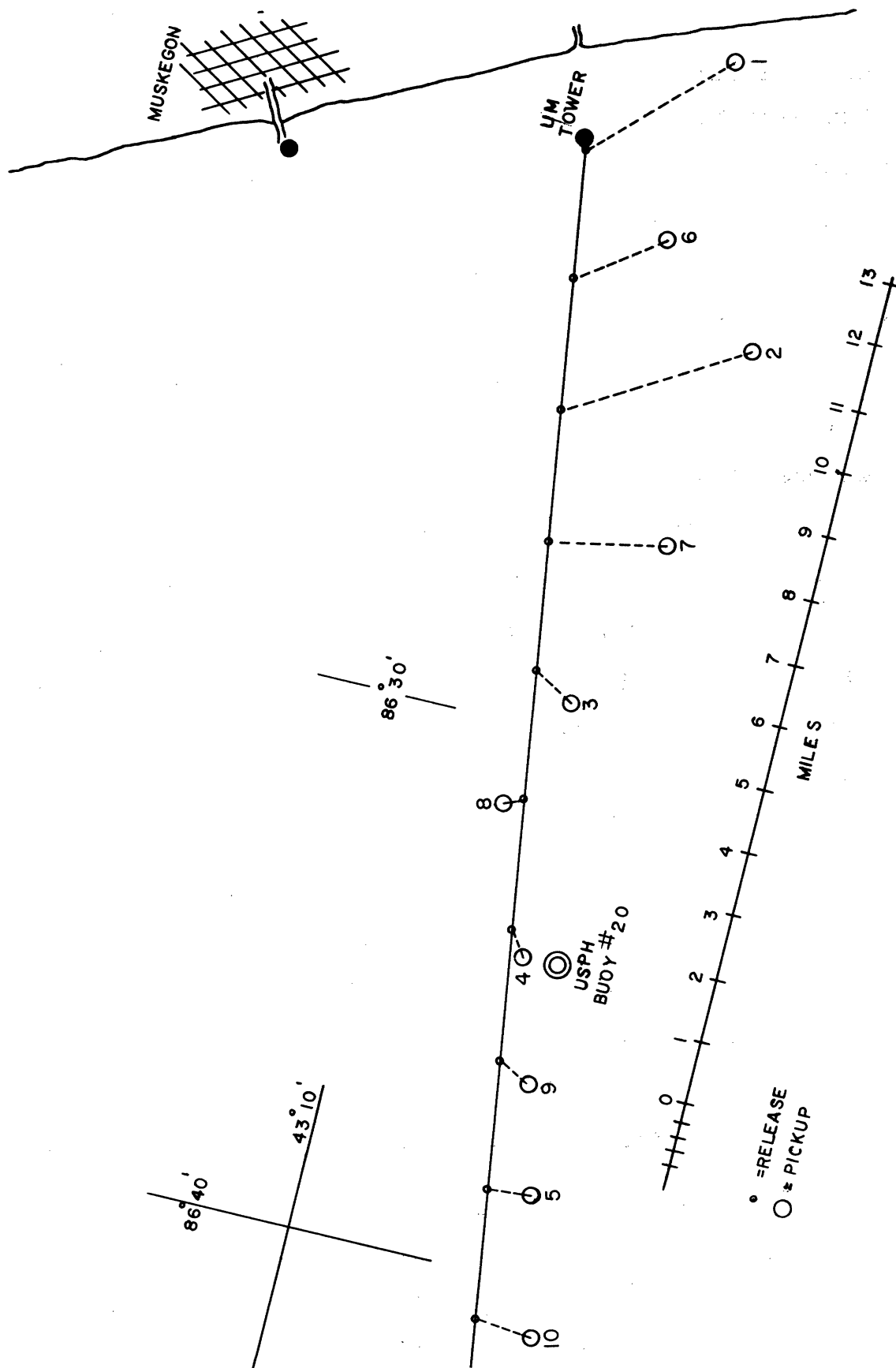


Fig. 2. Drogue study of 29 October 1963.

The drogue experiment of 29 October contributes to a degree of faith in the reality of the streaked current structure that was indicted by the computed currents.

Indirect Evidence for Current Streaks

Drift bottles released along the Racine to Grand Haven transect by the then U. S. Bureau of Fisheries on 17 July 1931 showed (Figure 3) an alternation of recoveries from north and south of the line of releases. This is at least compatible with the idea that initial bottle movements governed by current streaks may have determined the ultimate northward or southward location of recovery points. These studies are reported by Van Oosten (1963).

Johnson (1960) reported on multiple drift bottle releases at stations along the Grand Haven-Milwaukee line during July, August and September of 1954. His results are summarized in Figure 4. Varying degrees of alternation between northern and southern (and vice versa) recovery points are shown. In numerous instances bottles from a single release point had both northern and southern recoveries, as though these releases might have been at the interface between oppositely-flowing current streaks.

Both of the above reports show evidences of alternation in north and south recovery points in the southern basin of Lake Michigan. North of Frankfort, Michigan, these evidences become less abundant but do not disappear.

The meaning of the streaked current structure is at present not known.

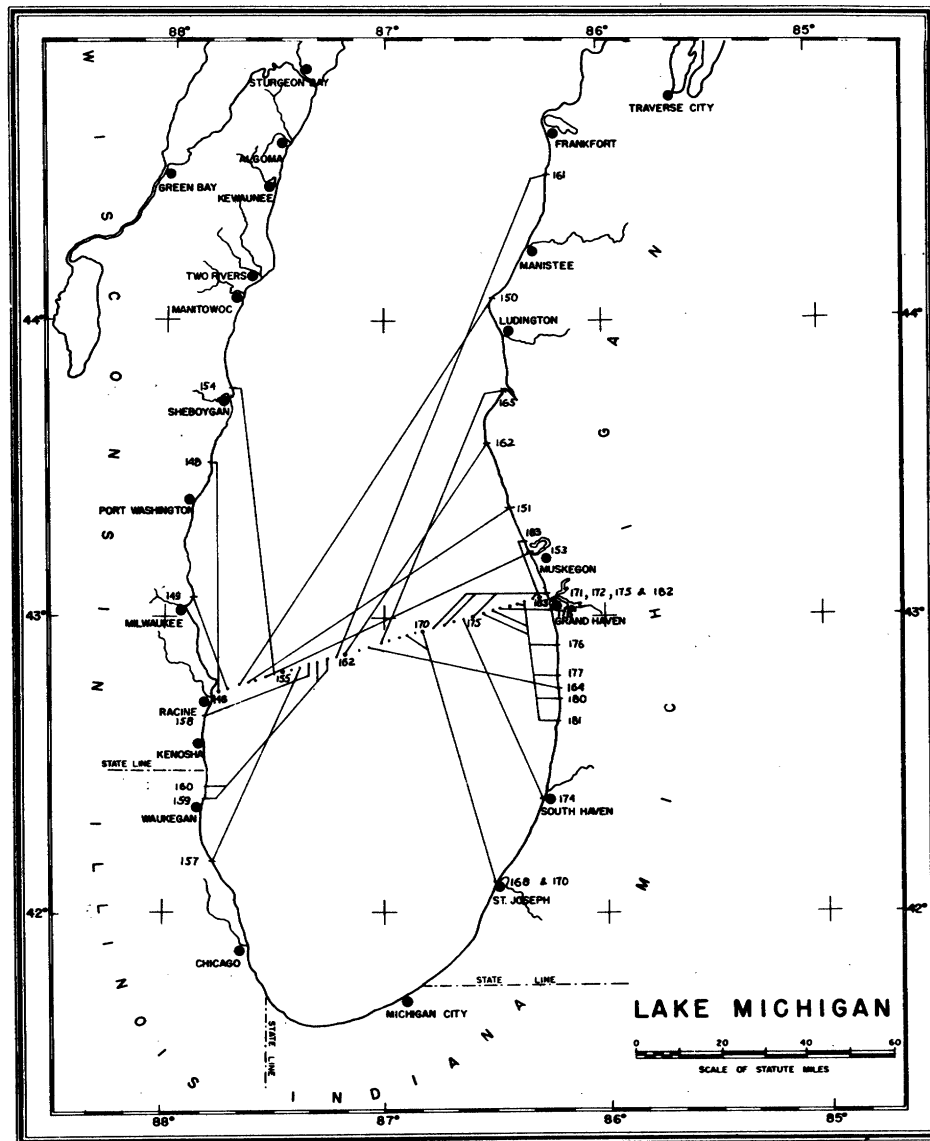


Fig. 3. Movements of bottles released along the transect, Racine to Grand Haven, July 17, 1931.

Volume Transport and Flushing Time

Although the dynamic height method of determining volume transport is still subject to some unanswered questions, it remains to date the fastest and most feasible means of obtaining such information where distances are great and/or where relative wealth of indicative detail is needed.

Perhaps the best assessment is still that of Sverdrup, Johnson and Fleming (1942, p. 394): "So many reservations have been made that it may appear as if the computed currents have little or no relation to the actual currents. Fortunately, however, most of the assumptions made lead only to minor errors, and currents can be correctly represented in the first approximation by means of the slopes of a series of isobaric surfaces relative to one reference surface."

To take the present volume transport results as first approximations is apparently within the validity of the method. It is certainly compatible with the intent with which these preliminary investigations are presented.

Even as first approximations, the present results allow us to take an initial step toward a more realistic determination of the flushing time of the southern basin of Lake Michigan.

Large volumes of water cross the mid-lake sill, both into and out of the southern basin. Water crossing the sill and entering the southern basin joins with the inflows from the rivers tributary to the southern basin in replacing the volume of water that is contained in the basin at a given instant. Continuity requires that the combined inflows be countermatched

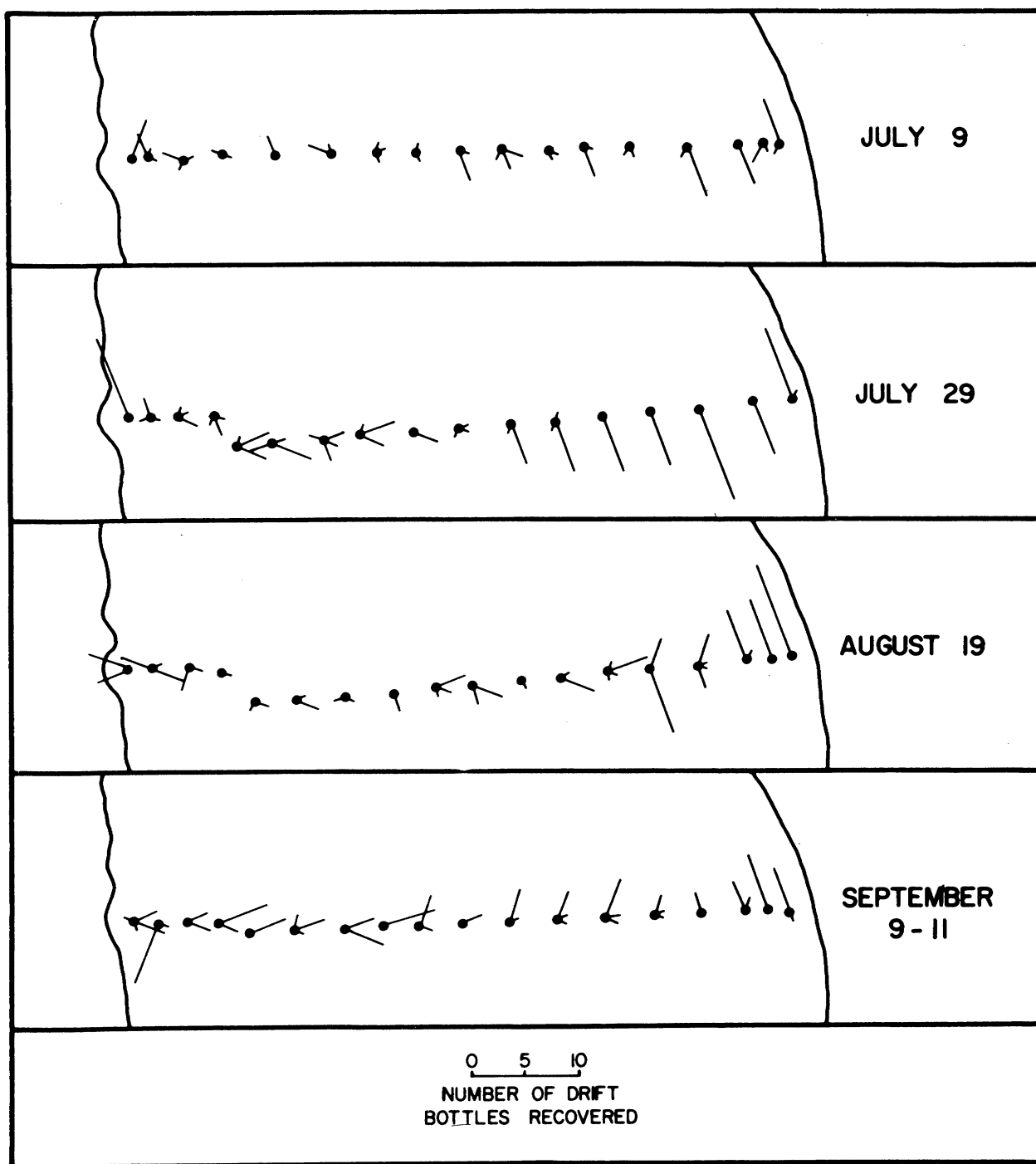


Fig. 4. Release stations, numbers recovered, and directions of recovery points of drift bottles that were released in 1954 on the Grand Haven-Milwaukee transect. For the transect in September bottles were released at the two easternmost stations on September 9 and the remaining stations on September 11.

by equal-volume net outflow from the southern basin. At present it is not known whether the compensatory outflow is subsurface and through the deep-water channels along the Michigan and Wisconsin shores, or whether it occurs as a counter-oscillation of the surface layers after release of set-up along shore, or as a combination of the two.

Water crossing the sill from southern basin to northern basin constitutes a direct subtraction from the volume content of the southern basin. In this case a compensatory net inflow is required, though its location and nature cannot be specified at present. The compensatory inflow, plus inflow from the rivers, works to replace a given instant's volume content of the southern basin.

It appears at present that the functional mechanism for the flushing of the southern basin is a combination of the addition of river inflows and a large-volume net transport over the sill.

From about May to about January, winds at Chicago, Muskegon and Milwaukee are dominantly from the south of west; in the rest of the months winds are chiefly from the north of west (U. S. Weather Bureau Tech. Paper 35, 1959, figs 8 through 19). These wind regimes may be expected to induce a northward net transport over the sill during summer and fall, and a net southward transport over the sill in mid-winter and spring.

The net transports over the sill should be accompanied in summer and fall by net southward compensatory counter-movement. In winter and spring the reverse condition should prevail.

Inflows entering a lake basin encounter several turbulent

mixing mechanisms among which waves, currents, and internal waves appear to be dominant, and to which are added local or periodic sinkings, upwellings, surface seiches, and periods of overturning. As a result of these turbulent phenomena inflowing waters more or less quickly lose their identity by being mixed into the receiving water.

Outflow sites are generally at distance from sites of inflow. In general, outflowing waters consist of more or less homogeneous mixtures of inflow and receiving water. Outflows balance the volume-content budget of a lake or basin. It is done, however, by removing compensatory volumes of "mixed" waters, not of "pure" receiving water.

Because influent waters become mixed with the receiving water, and because outflows are of mixed water, the flushing-out of the water that fills a lake or basin at a given instant is an exponential "die-away" process in which the rate of removal of original water at any time after the given instant is dependent upon the proportion of the original water mass that is still present.

The U. S. Geological Survey Water Supply Papers give the mean annual runoff of the rivers tributary to the lower basin of Lake Michigan as 4.2×10^{11} cubic feet, or about 14,000 cubic feet per second through the year.

Maximum net transport over the sill into the southern basin of the lake, in this study, is about 47,000 m³/sec or 1.65×10^6 cfs.

The sum of river and over-the-sill inflows under these

conditions is about 1.7×10^6 cfs which, divided into the 460×10^{11} cubic foot volume of the southern basin, gives 271×10^5 seconds or 314 days to bring in a volume of water equal to the volume of the southern basin.

Continuity would require under these conditions that 1/314th of the basin volume be discharged from the basin per day, an exchange ratio of 0.0032 per day. This maximum exchange ratio is used in the "die-away" equation

$$V_t = V_o e^{-.0032x}$$

where the subscripts o and t mean "original" and "at time" and x is number of days.

Considering flushing-out to be complete when 99% of the original basin water-content has been removed gives

$$V_t/V_o = 0.01 = e^{-.0032x}$$

$$\ln 0.01 = -.0032x$$

$$-4.60517 = -.0032x$$

$$x = 1439 \text{ days or } 3.9 \text{ years}$$

Minimum net transport over the sill, found in this study, was $3,800 \text{ m}^3/\text{sec}$ or 0.13×10^6 cfs. Combined with river inputs this gives 0.14×10^6 cfs total input. Dividing the basin volume by total input gives 3286×10^5 seconds or 3803 days to supply a volume of water equal to the basin content.

Volume-content balance requires under these conditions, the discharge of 1/3803th of basin volume per day or an exchange ratio of 0.00026 per day. With this minimum exchange ratio the die-away equation gives

$$V_t/V_o = 0.01 = e^{-.00026x}$$

$$\ln 0.01 = -.00026x$$

$$x = 17,712 \text{ days or } 48.5 \text{ years}$$

to flush out 99% of the southern basin volume.

Taking these two values as indicative of minimum and maximum flushing times, we may indicate a mean first approximation flushing time for the southern basin of Lake Michigan as being of the order of 26 years.

Comparison to Solute Accumulations

With regard to flushing characteristics three major types of water bodies may be recognized. One, typified by Great Salt Lake which has no outlet, may be called "basins of almost total accumulation." A second, typified by the usual river or stream, may be called "basins of almost no accumulations." The third, typified by the usual lake with an outlet and inlet(s), may be called "basins of partial accumulation."

Each basin is considered to lose some of the solutes contributed to it by 1) incorporation of solutes in its sediments and by 2) incorporation of solutes into biological products completely removed by man or predators.

In basins of almost total accumulation the sum of solutes present, plus those lost by the two means indicated, is about the total that has been contributed, and flushing time approaches infinity.

In basins of almost no accumulation (streams) the water-volume and solute contents of the basin (bed) are essentially equaled by those of the influent coming in in the next unit of

time and flushing time is close to one.

Basins of partial accumulation receive solutes via influent waters and discharge solutes via their effluents. Solute concentrations in the influent and effluent waters are usually different, and the concentrations of solutes observed in the basin waters is a reflection of

$$\text{influx} - (\text{losses} + \text{efflux}).$$

Since rates of loss to sediments and by removed biological products are relatively small, the concentration of solutes in a basin compared to the rate of their influx is a rough measure of the basin's effective accumulation-time.

Accumulation-time is also the effective number of time units that a given time-unit's contribution of solutes might be expected to remain in the basin.

Flushing time is the number of time-units that are necessary to remove a given instant's volume-content and its solutes from a basin.

The two concepts are essentially two views of the same process and computed times based on the two concepts are essentially comparable.

Unpublished results of USPHS Grant WP-00226-03 provide some accumulation-time estimates for comparison. From studies of solute concentrations in the southern basin of Lake Michigan and from the volume of the basin, the quantities of some solutes contained in the basin's water have been computed.

From studies of the solute concentrations in rivers tributary to the southern basin the annual contributions of

solutes to the basin have been computed.

For each of the solutes considered, the accumulation-time has been computed by

$$\frac{\text{Pounds of solute in basin water}}{\text{Pounds of solute contributed by rivers yearly}} = \text{Accumulation time}$$

The accumulation times available to be compared to the computed flushing times are:

Chloride	29 years
Sulfate	38 years
Phosphorus	6 years

If these are treated as first approximations, as were the flushing times, we may take the mean of the maximum and minimum values as a mean first approximation to compare with the mean first approximation flushing time.

Mean 1st approx. flushing time 26 years

Mean 1st approx. accumulation time 22 years

The agreement is good, though both types of results need to be refined by further repetitions.

As an initial working hypothesis we must consider Lake Michigan's southern basin to be flushed out only four times per century.

SUMMARY

This report is the first of a series which altogether comprise the final report on work done under the contract.

The primary goals of this section were the determination of volumes of water transported across the central sill of Lake Michigan and the effect of these water volumes on the flushing out of the lake's southern basin.

Large volumes of water were found to be crossing the sill in the period April through November. Maximum volume transports found were 44,000 m³/sec northward and 47,000 m³/sec southward. Minimum transports were 5,900 m³/sec northward and 3,900 m³/sec southward.

Volume transports across the sill are controlled by wind.

Volume transports across the sill are from 10 to 100 times the inflow via rivers, and constitute the primary means of flushing out the southern basin.

Computed flushing times of the southern basin, and computed solute-accumulations in the southern basin, both indicate that about 25 years must be taken as the first approximation of the flushing time of the southern basin.

Wind-induced currents involved in the volume transports across the sill occur in alternate streaks of northward and southward current. The meaning of the streaked nature of these currents is not yet known.

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Washington, D. C. 75 pp., 33 figures, 10 tables, appendix.

Table 1

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 10 August 1962

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
August 1962								
East Sector								
5	---	---	*350°	4	*040°	2	*160°	2
6	*080°	4	*120°	7	*110°	6	*050°	6
7	*060°	2	*290°	1	*190°	1	'260°	5
8	*320°	8	*260°	2	'270°	4	*290°	13
9	*340°	12	'050°	24	*020°	9	*060°	12
10	*050°	10	*070°	6	*070°	4	*080°	10
West Sector								
5	'010°	15	'180°	2	*050°	4	*090°	5
6	'110°	7	'090°	14	*120°	12	'150°	10
7	'160°	10	'230°	10	'260°	13	'220°	6
8	'060°	6	'260°	9	'270°	4	*300°	8
9	'030°	28	'020°	28	*040°	8	*030°	13
10	*040°	12	*340°	2	*140°	2	*090°	8

' Ship Weather Reports

* Weather Bureau land-station data, when ship reports not available

Table 2

Muskegon - Milwaukee

10 August 1962

Water-Volume Transports in the 2.5-mile x 60-meter Blocks, m^3/sec

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	2194	0	<u>2194 North</u>
2	2149	0	<u>2149 North</u>
3	280	1821	<u>1541 South</u>
4	0	6168	<u>6168 South</u>
5	110	5054	<u>4944 South</u>
6	0	12533	<u>12533 South</u>
7	0	4971	<u>4971 South</u>
8	4241	33	<u>4208 North</u>
9	2614	11	<u>2603 North</u>
10	70	3330	<u>3260 South</u>
11	8030	20	<u>8010 North</u>
12	2075	0	<u>2075 North</u>
13	6	3277	<u>3271 South</u>
14	56	1028	<u>972 South</u>
15	8761	0	<u>8761 North</u>
16	1643	0	<u>1643 North</u>
17	53	125	<u>72 South</u>
18	0	5245	<u>5245 South</u>
19	0	2139	<u>2139 South</u>
20	3460	104	<u>3356 North</u>
21	71	1688	<u>1617 South</u>
22	6604	0	<u>6604 North</u>
23	543	0	<u>543 North</u>
24	2390	287	<u>2103 North</u>
25	465	773	<u>308 South</u>
26	0	4433	<u>4433 South</u>
27	0	937	<u>937 South</u>
28	0	12037	<u>12037 South</u>
29	0	18615	<u>18615 South</u>
30	0	7212	<u>7212 South</u>
31	0	1254	<u>1254 South</u>
	<u>45815</u>	<u>93095</u>	<u>47280 South</u>

Table 3

Muskegon - Milwaukee

10 August 1962

Mean Velocities in Each of the 2.5-mile x 10-meter Blocks.

Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.054S	0	0	0	0	0
2	.026N	.023N	.003N	0	0	0
3	.039S	.006S	.004N	.003N	0	0
4	.255S	.138S	.016S	.002S	.0015S	.0002S
5	.050S	.050S	.020S	.001N	.001N	.0004N
6	.072S	.070S	.041S	.006S	.0005S	.00003S
7	.057S	.047S	.019S	.0007S	.0007S	.0003S
8	.031N	.044N	.028N	.003N	.0006S	.0003S
9	.024N	.027N	.014N	.00006S	.0002S	.00001S
10	.035S	.033S	.015S	.001N	.0005N	.0001N
11	.086N	.079N	.035N	.0003S	.0002S	.00003S
12	.009N	.024N	.017N	.001N	.0006N	.0001N
13	.017S	.039S	.025S	.0006S	.0001N	.00006N
14	.001S	.014S	.010S	.001N	.0003N	.00006N
15	.097N	.083N	.037N	.001N	.00008N	.00001N
16	.020N	.016N	.003N	.0007N	.0008N	.0003N
17	.0003S	.001S	.0009S	.001S	.0006S	.0002S
18	.076S	.044S	.011S	.0007S	.00007S	0
19	.020S	.018S	.012S	.003S	.0005S	.00003S
20	.050N	.030N	.006N	.002S	.0008S	.0002S
21	.019S	.018S	.005S	.002N	.0003N	.0002S
22	.079N	.059N	.023N	.003N	.0006N	.0002N
23	.001N	.002N	.006N	.002N	.002N	.0006N
24	.037N	.023N	.0002S	.003S	.003S	.0009S
25	.016S	.003S	.004N	.004N	.003N	.001N
26	.062S	.036S	.008S	.004S	.001S	.0003S
27	.011S	.007S	.002S	.002S	.001S	.0005S
28	.137S	.116S	.047S	.001S	.00006S	.00009S
29	.222S	.168S	.073S	.003S	0	0
30	.101S	.079S	0	0	0	0
31	.031S	0	0	0	0	0

Table 4

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 20 August 1962

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
August 1962								
East Sector								
11	*050°	4	*100°	2	*150°	2	*180°	
12	*190°	8	*160°	7	'200°	17	*210°	
13	'270°	17	'330°	22	*300°	9	'340°	
14	'340°	30	*360°	8	'020°	19	*340°	
15	*300°	10	'150°	6	*170°	3	*210°	
16	*240°	8	*210°	9	'250°	8	*280°	
17	*340°	9	'060°	13	*070°	4	*230°	
18	*310°	7	*090°	1	'270°	5	'210°	
19	*320°	4	'120°	11	'170°	17	'210°	
20	*260°	3	*230°	9	*260°	12	*280°	

West Sector

11	*090°	6	*080°	1	*170°	4	*160°	
12	*170°	11	*180°	9	'200°	14	'190°	
13	'280°	16	'300°	22	'290°	16	'340°	
14	'340°	30	*010°	8	'020°	19	*020°	
15	*050°	5	'150°	6	*220°	2	*210°	
16	*170°	7	'200°	17	'250°	8	*190°	
17	*040°	6	*340°	2	'140°	12	*070°	
18	'180°	13	'300°	6	'280°	5	'290°	
19	'090°	14	'160°	18	'170°	17	'210°	
20	'200°	10	*230°	4	'310°	13	'080°	

' Ship Weather Reports

* Weather Bureau land-station data, when ship reports not available

Table 5

Grand Haven- Milwaukee

20 August 1962

Water-Volume Transports in the 2-mile x 60-meter Blocks, $m^3/sec.$

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	7118	0	7118 North
2	22218	0	22218 North
3	3263	0	3263 North
4	3372	156	3216 North
5	7532	0	7532 North
6	0	3552	3552 South
7	137	3087	2950 South
8	0	9444	9444 South
9	0	7266	7266 South
10	3705	8	3697 North
11	11	1379	1368 South
12	0	3860	3860 South
13	0	5169	5169 South
14	4896	5	4891 North
15	140	379	239 South
16	0	4704	4704 South
17	4143	48	4095 North
18	0	2080	2080 South
19	1022	0	1022 North
20	0	913	913 South
21	53	3914	3861 South
22	0	5386	5386 South
23	6835	0	6835 North
24	8419	0	8419 North
25	5379	0	5379 North
26	4307	218	4089 North
27	650	0	650 North
28	18	1648	1630 South
29	0	1945	1945 South
30	202	4095	3893 South
31	2738	33	2705 North
32	5142	0	5142 North
33	2606	135	2471 North
34	36	1381	1345 South
35	54	703	649 South
36	2	2833	2831 South
37	6531	0	6531 North
38	4670	0	4670 North
39	3232	0	3232 North
	<u>108431</u>	<u>64341</u>	<u>44090 North</u>

Table 6

Grand Haven - Milwaukee

20 August 1962

Mean Velocities in Each of the 2-mile x 10-meter Blocks.

Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.129N	.092N	0	0	0	0
2	.282N	.234N	.135N	.039N	0	0
3	.023N	.043N	.028N	.005N	.002N	0
4	.072N	.033N	.005S	.00008S	.0003S	0
5	.111N	.089N	.033N	.0009N	.0003N	0
6	.070S	.036S	.003S	.001S	.0005S	0
7	.065S	.031S	.002N	.001N	.0005N	.0002N
8	.152S	.107S	.034S	.001S	0	0
9	.103S	.084S	.037S	.002S	0	0
10	.054N	.043N	.018N	.0005N	.0002S	.0001S
11	.017S	.017S	.009S	.0002S	.0003N	.0001N
12	.047S	.046S	.025S	.002S	.0001S	0
13	.075S	.061S	.024S	.000005S	.0004S	.0002S
14	.068N	.059N	.026N	.0002S	.0003N	.0001N
15	.003S	.006S	.003S	.003N	.001N	.0003N
16	.065S	.056S	.025S	.0008S	.0002S	.00001N
17	.059N	.050N	.021N	.0006S	.0007S	.0003S
18	.029S	.024S	.011S	.0009S	.0005S	.0002S
19	.019N	.010N	.0007N	.001N	.0005N	.0002N
20	.018S	.007S	.001S	.001S	.0008S	.0002S
21	.054S	.047S	.022S	.0006N	.0009N	.0002N
22	.080S	.056S	.024S	.005S	.002S	.0005S
23	.089N	.080N	.040N	.003N	.0009N	.0003N
24	.112N	.103N	.046N	.0006N	.00008N	.00008N
25	.074N	.057N	.028N	.005N	.003N	.0008N
26	.073N	.048N	.013N	.004S	.002S	.0009S
27	.005N	.009N	.004N	.001N	.0009N	.0004N
28	.019S	.021S	.011S	.0001S	.0004N	.0002N
29	.029S	.021S	.007S	.001S	.001S	.0004S
30	.060S	.048S	.019S	.003N	.003N	.0009N
31	.029N	.036N	.020N	.0003S	.0007S	.0001S
32	.082S	.056S	.019S	.002S	.001S	.0004S
33	.048N	.030N	.003N	.004S	.00005N	.0002N
34	.015S	.020S	.007S	.001N	.001S	.0006S
35	.010S	.009S	.002S	.002N	0	0
36	.054S	.027S	.007S	.00009N	0	0
37	.081N	.082N	.041N	0	0	0
38	.086N	.060N	0	0	0	0
39	.067N	.033N	0	0	0	0

Table 7

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 3 November 1962

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
October - November 1962								
East Sector								
29	---	---	*040°	19	*090°	3	*220°	
30	*220°	21	*230°	23	*330°	22	*340°	1
31	*330°	7	*350°	24	*350°	28	*330°	2
1	*330°	7	*340°	16	---	---	*350°	
2	*350°	9	*020°	12	*210°	8	*070°	1
3	*090°	16	---	---	*070°	18	*050°	1

West Sector

29	---	---	*020°	18	*070°	6	*210°	1
30	*220°	21	*230°	23	*310°	26	*350°	2
31	*360°	16	*350°	24	*010°	28	*330°	2
1	*350°	9	*340°	19	*300°	12	*350°	
2	*350°	9	*110°	4	*060°	09	*230°	
3	*090°	16	*090°	17	*080°	11	*030°	1

* Ship Weather Reports

* Weather Bureau land-station data, when ship reports not available

Table 8

Grand Haven - Milwaukee

3 November 196

Water-Volume Transports in the 2-mile x 60-meter Blocks, m³/sec.

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	0	712	712 South
2	1394	0	1394 North
3	24244	0	24244 North
4	13207	10	13197 North
5	0	3147	3147 South
6	7213	41	7172 North
7	0	6312	6312 South
8	6483	0	6483 North
9	5829	21	5808 North
10	0	6258	6258 South
11	35	1302	1267 South
12	0	7168	7168 South
13	2540	227	2313 North
14	2871	0	2871 North
15	13499	0	13499 North
16	20	7443	7423 South
17	1873	0	1873 North
18	1177	481	696 North
19	6391	0	6391 North
20	734	5	729 North
21	0	9221	9221 South
22	4637	0	4637 North
23	31	622	591 South
24	322	1338	1016 South
25	5953	0	5953 North
26	0	9275	9275 South
27	0	7392	7392 South
28	196	627	431 South
29	0	1780	1780 South
30	0	4087	4087 South
31	0	11493	11493 South
32	4562	0	4562 North
33	0	4995	4995 South
34	0	6045	6045 South
35	0	8126	8126 South
36	0	330	330 South
37	0	1196	1196 South
38	1229	0	1229 North
39	2289	0	2289 North
	<u>106729</u>	<u>99654</u>	<u>7075 North</u>

Table 9

Grand Haven - Milwaukee

3 November 1962

Mean Velocities in Each of the 2-mile x 10-meter Blocks.

Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.022S	0	0	0	0	0
2	.020N	.012N	.007N	.004N	0	0
3	.195N	.175N	.151N	.126N	.081N	.024N
4	.100N	.103N	.105N	.078N	.025N	.003S
5	.032S	.028S	.023S	.011S	.002S	.001S
6	.074N	.071N	.057N	.021N	.001S	.001N
7	.048S	.055S	.053S	.040S	0	0
8	.085N	.067N	.035N	.015N	0	0
9	.090N	.051N	.021N	.013N	.006N	.001S
10	.065S	.057S	.040S	.023S	.008S	.001S
11	.006S	.012S	.014S	.008S	0	.001N
12	.044S	.044S	.044S	.046S	.034S	.009S
13	.034N	.024N	.015N	.006N	.003S	.004S
14	.014N	.020N	.025N	.018N	.008N	.004N
15	.126N	.112N	.088N	.058N	.029N	.007N
16	.069S	.065S	.056S	.034S	.008S	.001N
17	.025N	.015N	.010N	.006N	.001N	0
18	.012S	.003S	.006N	.016N	.013N	.002N
19	.059N	.056N	.050N	.028N	.005N	0
20	.002N	.006N	.009N	.006N	0	0
21	.066S	.071S	.076S	.056S	.018S	.001S
22	.035N	.035N	.033N	.029N	.013N	0
23	.011S	.006S	.002S	0	0	0
24	.008N	.002N	.008S	.019S	.013S	.001S
25	.046N	.042N	.042N	.038N	.017N	.001N
26	.077S	.073S	.069S	.050S	.018S	.001S
27	.060S	.052S	.047S	.043S	.028S	0
28	.008S	.007S	.005S	.001N	.005N	0
29	.005S	.008S	.011S	.016S	.016S	0
30	.019S	.019S	.022S	.026S	.028S	.013S
31	.108S	.091S	.071S	.049S	.029S	.010S
32	.002N	.016N	.028N	.037N	.040N	.020N
33	.015S	.022S	.029S	.036S	.036S	.016S
34	.037S	.036S	.035S	.034S	.031S	.015S
35	.069S	.063S	.055S	.042S	.024S	0
36	.006S	.003S	.001S	0	0	0
37	.016S	.013S	.008S	0	0	0
38	.022N	.016N	0	0	0	0
39	.071N	0	0	0	0	0

Table 10

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 9 November 1962

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
November 1962								
East Sector								
4	---	---	'320°	16	*230°	17	*240°	11
5	*100°	8	'050°	21	*040°	20	*020°	14
6	*320°	4	*080°	4	'170°	21	*190°	28
7	*170°	12	'210°	29	*250°	24	*270°	24
8	*280°	12	'350°	16	*330°	7	'350°	19
9	*040°	3	*050°	2	*090°	1	*130°	10
West Sector								
4	'360°	15	'320°	16	'230°	17	*240°	11
5	'300°	34	'050°	21	'040°	20	'020°	14
6	'040°	14	'160°	11	'170°	21	'190°	28
7	'180°	30	'210°	26	'250°	24	'270°	24
8	'290°	28	'350°	16	*330°	7	'350°	19
9	*360°	7	'080°	10	*090°	1	'130°	10

' Ship Weather Reports

* Weather Bureau land-station data, when ship reports not available

Table 11

Racine - Grand Haven

9 November 1962

Water-Volume Transports in the 2-mile x 60-meter Blocks, m^3/sec .

<u>Block</u>	<u>South Transport</u>	<u>North Transport</u>	<u>Net Transport</u>
1	0	4707	4707 North
2	164	0	164 South
3	296	0	296 South
4	2486	0	2486 South
5	3180	0	3180 South
6	6448	0	6448 South
7	1297	24	1273 South
8	2933	0	2933 South
9	281	477	196 North
10	4007	3	4004 South
11	3653	0	3653 South
12	303	310	7 North
13	2057	0	2057 South
14	556	888	332 North
15	0	4310	4310 North
16	0	2915	2915 North
17	0	2406	2406 North
18	0	5844	5844 North
19	6510	0	6510 South
20	7450	0	7450 South
21	8	581	573 North
22	0	6404	6404 North
23	0	4477	4477 North
24	0	6543	6543 North
25	4835	0	4835 South
26	3702	0	3702 South
27	0	4625	4625 North
28	0	4009	4009 North
29	376	2644	2268 North
30	6719	0	6719 South
31	7026	0	7026 South
32	0	12357	12357 North
33	0	3509	3509 North
34	0	31730	31730 North
35	0	21102	21102 North
36	19112	0	19112 South
37	2181	0	2181 South
	<u>85580</u>	<u>119865</u>	<u>34285 North</u>

Table 12

Racine - Grand Haven

9 November 1962

Mean Velocities in Each of the 2-mile x 10-meter Blocks.
 Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.146S	0	0	0	0	0
2	.005N	0	0	0	0	0
3	.006N	.003N	0	0	0	0
4	.036N	.026N	.015N	0	0	0
5	.036N	.028N	.021N	.014N	0	0
6	.043N	.041N	.038N	.034N	.030N	.014N
7	.016N	.011N	.008N	.005N	.001N	.0008S
8	.024N	.021N	.018N	.013N	.010N	.004N
9	.006S	.006S	.003S	.002N	.005N	.003N
10	.046N	.036N	.025N	.014N	.004N	.0001S
11	.028N	.025N	.023N	.019N	.014N	.005N
12	.006S	.003S	.0007S	.003N	.004N	.002N
13	.022N	.017N	.013N	.007N	.004N	.002N
14	.017S	.009S	.001S	.007N	.008N	.003N
15	.035S	.032S	.028S	.024S	.013S	.002S
16	.020S	.018S	.016S	.016S	.014S	.007S
17	.023S	.018S	.013S	.009S	.008S	.005S
18	.037S	.037S	.037S	.034S	.026S	.010S
19	.041N	.043N	.043N	.038N	.027N	.010N
20	.038N	.040N	.044N	.053N	.043N	.013N
21	.006S	.004S	.004S	.003S	.0009S	.0003N
22	.059S	.051S	.042S	.032S	.014S	.005S
23	.024S	.027S	.029S	.032S	.022S	.005S
24	.038S	.038S	.038S	.038S	.036S	.017S
25	.041N	.036N	.030N	.023N	.015N	.006N
26	.028N	.026N	.023N	.019N	.014N	.006N
27	.062S	.035S	.020S	.015S	.009S	.003S
28	.050S	.031S	.015S	.010S	.012S	.007S
29	.047S	.027S	.008S	.002N	.006N	.004N
30	.030N	.021N	.029N	.060N	.054N	.015N
31	.072N	.064N	.048N	.026N	.008N	.001N
32	.105S	.099S	.088S	.066S	.026S	.0002S
33	.024S	.026S	.027S	.023S	.009S	.00003S
34	.252S	.217S	.188S	.163S	.121S	.045S
35	.191S	.162S	.129S	.093S	.059S	.021S
36	.244N	.198N	.152N	0	0	0
37	.037N	.030N	0	0	0	0

Table 13

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 17 April 1963

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
April 1963								
East Sector								
12	*040°	5	'010°	15	'340°	7	*310°	9
13	*340°	4	*050°	6	*330°	5	*340°	13
14	*030°	9	'320°	13	*310°	5	*320°	14
15	*340°	9	*360°	1	*320°	1	*220°	3
16	*210°	5	*170°	10	*170°	14	'160°	30
17	*180°	15	*180°	11	*150°	9	'180°	17
West Sector								
12	*070°	5	'010°	15	'340°	7	'120°	13
13	*070°	5	'330°	9	'340°	8	'360°	9
14	'360°	9	*270°	2	*260°	4	*020°	12
15	*080°	8	*200°	2	*200°	9	*170°	8
16	*160°	10	*160°	12	*160°	16	'160°	30
17	*230°	10	*180°	11	*210°	6	'200°	20

' Ship Weather Reports

* Weather Bureau land-station data, when ship reports not available

Table 14

Milwaukee - Grand Haven

17 April 1963

Water-Volume Transports in the 2-mile x 60-meter Blocks, m³/sec.

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	680	0	680 North
2	1445	0	<u>1445 North</u>
3	0	0	0
4	1620	0	1620 North
5	0	1620	<u>1620 South</u>
6	590	0	590 North
7	0	2116	2116 South
8	0	0	0
9	0	671	671 South
10	671	0	<u>671 North</u>
11	0	0	0
12	468	0	468 North
13	0	310	310 South
14	0	828	828 South
15	346	0	<u>346 North</u>
16	0	346	346 South
17	1419	0	<u>1419 North</u>
18	0	0	0
19	654	0	<u>654 North</u>
20	0	0	0
21	0	523	523 South
22	910	0	910 North
23	0	386	386 South
24	386	0	<u>386 North</u>
25	0	0	0
26	0	0	0
27	0	386	386 South
28	0	0	0
29	0	2922	2922 South
30	0	317	317 South
31	0	0	0
32	0	0	0
33	0	0	0
34	0	0	0
35	0	1477	1477 South
36	6	1172	1166 South
37	0	748	748 South
38	0	389	389 South
	<u>9145</u>	<u>14211</u>	<u>5016 South</u>

Table 15

Milwaukee - Grand Haven

17 April 1963

Mean Velocities in Each of the 2-mile x 10-meter Blocks.
 Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.008N	.007N	.005N	.002N	0	0
2	.010N	.010N	.009N	.008N	.005N	.002N
3	0	0	0	0	0	0
4	.015N	.013N	.010N	.007N	.004N	.001N
5	.015S	.013S	.010S	.007S	.004S	.001S
6	.004N	.004N	.004N	.003N	.002N	.001N
7	.020S	.016S	.013S	.009S	.005S	.002S
8	0	0	0	0	0	0
9	.005S	.005S	.005S	.004S	.002S	.001S
10	.005N	.005N	.005N	.004N	.002N	.001N
11	0	0	0	0	0	0
12	.005N	.003N	.002N	.002N	.002N	.001N
13	.002S	.002S	.002S	.002S	.002S	.001S
14	.008S	.006S	.005S	.004S	.002S	.001S
15	.002N	.002N	.002N	.002N	.002N	.001N
16	.002S	.002S	.002S	.002S	.002S	.001S
17	.012N	.011N	.009N	.007N	.004N	.001N
18	0	0	0	0	0	0
19	.006N	.005N	.004N	.003N	.002N	.001N
20	0	0	0	0	0	0
21	.004S	.004S	.004S	.003S	.002S	.001S
22	.007N	.007N	.006N	.005N	.003N	.001N
23	.003S	.003S	.002S	.002S	.002S	.001S
24	.003N	.003N	.002N	.002N	.002N	.001N
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	.003S	.003S	.002S	.002S	.002S	.001S
28	0	0	0	0	0	0
29	.028S	.023	.018S	.012S	.007S	.002S
30	.003S	.003S	.002S	.001S	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	0	0	0	0	0	0
34	0	0	0	0	0	0
35	.014S	.012S	.009S	.006S	.004S	.001S
36	.013S	.010S	.008S	.004S	.001S	0
37	.010S	.007S	.004S	.001S	0	0
38	.002S	.002S	.002S	.002S	.002S	.001S

Table 16

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 20 May 1963

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
May 1963								
East Sector								
15	'090°	34	*010°	5	*070°	2	*200°	4
16	*150°	5	*010°	4	'360°	13	* Calm	
17	*050°	3	*090°	7	'110°	17	*040°	6
18	*330°	7	*260°	5	*230°	10	*290°	15
19	*270°	14	*260°	9	*260°	4	*210°	14
20	*300°	10	*300	6	*280°	9	'180°	14
West Sector								
15	'090°	34	*060°	4	*340°	3	*070°	8
16	'030°	10	'220°	8	'010°	12	*050°	7
17	*030°	9	*050°	4	'270°	13	*010°	9
18	'210°	12	*200°	5	'250°	9	*270°	16
19	'010°	6	*250°	7	*190°	6	*240°	13
20	*280°	12	*320°	4	*290°	7	*270°	11

' Ship Weather Reports

* Weather Bureau land-station data, when ship reports not available

Table 17

Grand Haven - Milwaukee

20 May 1963

Water-Volume Transports in the 2-mile x 60-meter Blocks, $m^3/sec.$

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	648	0	648 North
2	2910	0	2910 North
3	2241	0	2241 North
4	625	0	625 North
5	333	0	333 North
6	0	883	883 South
7	78	0	78 North
8	67	0	67 North
9	0	571	571 South
10	0	258	258 South
11	0	0	0
12	50	0	50 North
13	27	0	27 North
14	180	0	180 North
15	0	28	28 South
16	469	0	469 North
17	333	0	333 North
18	215	0	215 North
19	0	88	88 South
20	0	51	51 South
21	0	604	604 South
22	655	0	655 North
23	0	357	357 South
24	306	0	306 North
25	0	271	271 South
26	0	35	35 South
27	0	107	107 South
28	281	0	281 North
29	382	0	382 North
30	0	50	50 South
31	180	0	180 North
32	0	145	145 South
33	86	0	86 North
34	75	0	75 North
35	0	218	218 South
36	0	494	494 South
37	0	0	0
	<u>10141</u>	<u>4160</u>	<u>5981 North</u>

Table 18

Grand Haven - Milwaukee

20 May 1963

Mean Velocities in Each of the 2-mile x 10-meter Blocks.
 Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.013N	.007N	.001N	0	0	0
2	.061N	.025N	.004N	0	0	0
3	.031N	.020N	.011N	.005N	.002N	.001N
4	.007N	.005N	.004N	.002N	.001N	0
5	.004N	.003N	.002N	.001N	.001N	0
6	.008S	.007S	.005S	.004S	.003S	.001S
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	.005S	.005S	.004S	.002S	.001S	0
10	.003S	.002S	.001S	.001S	.001S	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	.002N	.001N	.001N	.001N	0	0
15	0	0	0	0	0	0
16	.005N	.004N	.003N	.002N	.001N	0
17	.003N	.003N	.002N	.001N	.001N	0
18	.002N	.002N	.001N	.001N	0	0
19	.001S	.001S	0	0	0	0
20	0	0	0	0	0	0
21	.005S	.005S	.004S	.003S	.002S	.001S
22	.006N	.005N	.004N	.003N	.002N	.001N
23	.003S	.003S	.002S	.002S	.001S	0
24	.003N	.002N	.002N	.001N	.001N	0
25	.003S	.002S	.002S	.001S	.001S	0
26	0	0	0	0	0	0
27	.001S	.001S	.001S	.001S	0	0
28	.003N	.002N	.002N	.001N	.001N	0
29	.003N	.003N	.002N	.002N	.001N	.001N
30	0	0	0	0	0	0
31	.002N	.001N	.001N	.001N	0	0
32	.001S	.001S	.001S	.001S	0	0
33	.001N	.001N	.001N	0	0	0
34	.001N	.001N	.001N	0	0	0
35	.007S	0	0	0	0	0
36	.015S	0	0	0	0	0
37	0	0	0	0	0	0

Table 19

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 24 June 1963

Date	<u>0000GMT</u>		<u>0600GMT</u>		<u>1200GMT</u>		<u>1800GMT</u>	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
June 1963								
East Sector								
18	---	---	Calm		*170°	1	*310°	2
19	*210°	4	*170°	7	*220°	8	*220°	14
20	*210°	14	*290°	4	*330°	11	*340°	10
21	*350°	11	*020°	7	*340°	4	*330°	11
22	*330°	9	*180°	2	*340°	3	*040°	3
23	*290°	5	*060°	2	*110°	3	*150°	5
24	*140°	4	*110°	3	*090°	3	*190°	4
West Sector								
18	---	---	*230°	2	*010°	2	*110°	3
19	*130°	7	*200°	6	*200°	7	*220°	13
20	*190°	10	*330°	2	*030°	14	*020°	14
21	*050°	9	*360°	7	*010°	5	*030°	8
22	*070°	7	*230°	2	*000°	Calm	*110°	6
23	*060°	6	*100°	4	*140°	2	*110°	8
24	*070°	7	*050°	3	*060°	2	*110°	7

* Weather Bureau land-station data.

Table 20

Grand Haven - Port Washington

24 June 1963

Water-Volume Transports in the 2-mile x 60-meter Blocks, $m^3/sec.$

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	100	0	100 North
2	0	1292	1292 South
3	0	1394	1394 South
4	718	11	707 North
5	407	120	287 North
6	0	1464	1464 South
7	0	4090	4090 South
8	5352	0	5352 North
9	112	0	112 North
10	0	489	489 South
11	1513	0	1513 North
12	593	0	593 North
13	0	644	644 South
14	247	13	234 North
15	0	981	981 South
16	448	779	331 South
17	650	0	650 North
18	407	621	215 South
19	1597	0	1597 North
20	186	223	37 South
21	87	1581	1494 South
22	2	837	835 South
23	2391	0	2391 North
24	0	1071	1071 South
25*	0	0	0
26	0	1495	1495 South
27	0	4252	4252 South
28	6391	0	6391 North
29	353	28	326 North
30	0	3499	3499 South
31	125	1611	1486 South
32	2587	0	2587 North
33	1537	329	1209 North
34	736	0	736 North
35	784	0	784 North
36	0	1607	1607 South
37	0	1051	1051 South
38	280	195	85 North
39	0	601	601 South
	<u>27603</u>	<u>30278</u>	2675 South

*Leg runs north-south

Table 21

Grand Haven - Port Washington

24 June 1963

Mean Velocities in Each of the 2-mile x 10-meter Blocks.
 Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.002N	.001N	0	0	0	0
2	.022S	.014S	.004S	0	0	0
3	.024S	.015S	.004S	0	0	0
4	.013N	.007N	.002N	0	0	0
5	.004S	.008N	.004N	.001N	0	0
6	.021S	.017S	.007S	.001S	0	0
7	.036S	.043S	.032S	.014S	.002S	0
8	.071S	.051S	.032S	.012S	.001S	0
9	.002S	.001S	0	0	0	0
10	.008S	.004S	.002S	.001S	0	0
11	.014N	.013N	.010N	.006N	.003N	.001N
12	.012N	.004N	.001N	.001N	.001N	0
13	.008S	.003S	.003S	.003S	.002S	.001S
14	0	.001N	.002N	.002N	.002N	.001N
15	.011S	.010S	.006S	.003S	.001S	0
16	.024S	.001N	.007N	.004N	.001N	0
17	.004N	.007N	.007N	.002N	.001N	0
18	.013N	.004S	.009S	.004S	.002S	.001S
19	.020N	.016N	.008N	.003N	.002N	0
20	.007S	0	.002N	.002N	.001N	0
21	.040S	.009S	.002N	.001N	0	0
22	.016S	.008S	.002S	.001S	0	0
23	.052N	.019N	.002N	.001N	0	0
24	.014S	.008S	.006S	.003S	.002S	.001S
25*	0	0	0	0	0	0
26	.015S	.015S	.008S	.004S	.003S	.001S
27	.068S	.031S	.018S	.010S	.005S	.001S
28	.094N	.052N	.027N	.015N	.008N	.003N
29	.001S	.004N	.004N	.002N	.001N	0
30	.056S	.042S	.009S	.001S	0	0
31	.047S	.003S	.004N	0	0	0
32	.056N	.021N	.002N	.001N	.001N	0
33	.034N	.013N	.003S	.004S	.002S	.001S
34	.018N	0	.001N	.001N	.001N	0
35	.010N	.008N	.003N	.002N	.001N	0
36	.030S	.016S	.003S	0	0	0
37	.006S	.008S	.009S	.006S	.003S	.001S
38	.009N	0	.004S	.001S	0	0
39	.013S	.005S	0	0	0	0

*Leg runs north-south

Table 22

Lake Michigan Winds on Day of Transect and Preceding Days.

Transect of 24 July 1963

Date	0000GMT		0600GMT		1200GMT		1800GMT	
	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots	Wind from	Speed knots
July 1963								
East Sector								
19	---	---	*220°	9	*200°	10	*270°	8
20	*210°	4	*240°	4	*330°	11	*340°	10
21	*330°	10	*250°	2	*260°	4	*290°	11
22	*320°	8	*270°	6	*260°	3	*270°	8
23	*040°	7	*070°	3	*060°	5	*090°	10
24	*050°	4	*090°	5	*100°	2	*120°	2
West Sector								
19	---	---	*216°	8	*240°	7	*310°	2
20	*010°	3	*250°	4	*310°	11	*340°	12
21	*360°	6	*220°	2	*270°	6	*320°	7
22	*050°	10	*240°	3	Calm		*050°	3
23	*090°	5	*060°	4	*010°	5	*070°	7
24	*030°	8	*020°	3	*100°	3	*090°	6

* Weather Bureau land-station data.

Table 23

Muskegon - Milwaukee

24 July 1963

Water-Volume Transports in the 2-mile x 60-meter Blocks, m³/sec.

<u>Block</u>	<u>North Transport</u>	<u>South Transport</u>	<u>Net Transport</u>
1	3151	0	3151 North
2	332	294	38 North
3	2410	40	2370 North
4	0	1110	1110 South
5	62	1099	1037 South
6	4	794	790 South
7	0	2355	2355 South
8	737	0	737 North
9	2094	231	1863 North
10	46	309	263 South
11	2212	0	2212 North
12	146	144	2 North
13	825	0	825 North
14	76	1796	1720 South
15	135	290	155 South
16	71	455	384 South
17	0	326	326 South
18	237	1890	1654 South
19	3615	0	3615 North
20	185	1985	1800 South
21	0	3410	3410 South
22	57	398	341 South
23	3542	0	3542 North
24	2866	0	2866 North
25	578	2	576 North
26	0	1565	1565 South
27	20	1465	1445 South
28	660	0	660 North
29	382	114	268 North
30	0	1508	1508 South
31	0	3154	3154 South
32	3043	0	3043 North
33	191	486	296 South
34	3534	0	3534 North
35	1184	0	1184 North
36	0	1246	1246 South
	<u>32395</u>	<u>26466</u>	<u>5927 North</u>

Table 24

Muskegon - Milwaukee

24 July 1963

Mean Velocities in Each of the 2-mile x 10-meter Blocks.
 Mean Velocity, m/sec = Block Net Transport/Block Area.

Block	0-10m	10-20m	20-30m	30-40m	40-50m	50-60m
1	.088N	.010N	0	0	0	0
2	.009N	.009S	.001N	0	0	0
3	.065N	.010N	.001S	.001S	0	0
4	.007S	.002S	.009S	.009S	.006S	.002S
5	.025S	.009S	.001S	.001N	.001N	0
6	.024S	0	.001S	0	0	0
7	.043S	.021S	.006S	.003S	.001S	0
8	.002N	.006N	.007N	.004N	.003N	.001N
9	.051N	.014N	.002S	.002S	.002S	.001S
10	.001N	.001S	.002S	.003S	.002S	.001S
11	.034N	.015N	.009N	.006N	.004N	.001N
12	.004S	0	.001N	.001N	.001N	.001N
13	.020N	0	.002N	.002N	.001N	0
14	.048S	.008S	0	.001N	.001N	0
15	.009S	.004N	0	0	0	0
16	.009S	.005S	.001N	.001N	0	0
17	.002S	.001S	.002S	.003S	.002S	.001S
18	.048S	.011S	.002N	.003N	.002N	.001N
19	.087N	.020N	.004N	.002N	0	0
20	.062S	.003N	.002N	0	0	0
21	.081S	.022S	.002S	.001S	0	0
22	.004S	.006S	.003S	.001N	.001N	0
23	.078N	.024N	.006N	.002N	0	0
24	.066N	.020N	.003N	.001N	0	0
25	.015N	.003N	0	0	0	0
26	.026S	.013S	.005S	.003S	.001S	0
27	.040S	.005S	0	0	0	0
28	.012N	.003N	.003N	.002N	.001N	0
29	.010N	.002N	.002S	.001S	.001S	0
30	.030S	.014S	.002S	0	0	0
31	.053S	.032S	.008S	.003S	.001S	0
32	.045N	.031N	.011N	.044N	.002N	.001N
33	.005N	.001N	.007S	.005S	.003S	.001S
34	.082N	.017N	.006N	.003N	.002N	.001N
35	.023N	.008N	.003N	.002N	.001N	0
36	.024S	.009S	.005S	.001S	0	0

APPENDIX

BATHYTHERMOGRAPH DATA

Muskegon to Milwaukee
10 August 1962

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	Corr.
43°13.3', 86°21.6'		
6	0	16.5
	8.0	15.5
	11.0	13.5
	13.5	10.9
	14.0	7.4
43°13.0', 86°23.7'		
7	0	17.5
	4.0	17.2
	10.5	15.1
	13.0	13.8
	17.5	5.9
	30.0	5.8
43°12.6', 86°26.8'		
8	0	18.4
	6.0	17.9
	11.0	13.5
	12.0	10.7
	20.5	5.5
	22.0	5.4
	48.0	5.0
43°12.2', 86°29.9'		
9	0	18.6
	1.0	18.5
	7.5	18.4
	9.0	18.3
	16.0	6.2
	21.0	5.0
	30.0	4.6
	93.0	4.3
43°11.8', 86°30.0'		
10	0	18.8
	3.0	18.6
	17.0	18.0
	23.0	6.1
	42.0	4.7
	113.0	4.3
43°11.4', 86°36.1'		
11	0	18.4
	5.0	18.2
	14.0	18.1
	17.0	17.8
	19.0	16.5
	25.0	8.0
	29.0	6.0
	35.0	4.9
	50.0	4.4
	112.0	4.2
43°11.0', 86°39.2'		
12	0	18.7
	3.0	18.4
	16.0	18.0
	26.0	12.0
	27.5	9.0
	36.0	5.8

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	Corr.
43°10.7', 86°42.2'		
13	0	18.6
	5.0	18.3
	14.0	18.2
	17.0	18.1
	20.5	17.2
	24.0	15.0
	26.0	11.5
	31.0	7.3
	36.5	6.0
	43.0	5.0
	48.0	4.6
	114.5	4.5
43°10.4', 86°45.1'		
14	0	19.3
	1.0	18.8
	9.0	18.5
	16.0	18.4
	18.5	18.0
	22.5	16.0
	24.0	12.0
	25.0	9.8
	28.5	6.8
	36.0	5.4
	42.0	5.0
	58.5	4.7
	112.0	4.6
43°10.1', 86°47.9'		
15	0	19.8
	0.5	19.0
	6.0	18.6
	14.0	18.5
	19.0	18.1
	21.0	17.0
	24.0	9.0
	25.0	7.6
	34.0	5.5
	45.0	5.1
	54.0	4.9
	59.0	4.5
	102.0	4.5
	105.0	4.6
43°10.0', 86°50.9'		
16	0	19.8
	2.0	18.8
	5.5	18.6
	19.0	18.3
	21.0	17.7
	25.0	10.0
	26.5	8.8
	29.0	6.3
	31.0	6.2

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	Corr.
43°09.6', 86°54.4'		
16	33.0	5.5
	36.0	5.2
	59.0	4.6
	99.0	4.6
	103.0	4.7
43°09.6', 86°54.4'		
17	0	19.8
	2.0	19.0
	3.5	18.8
	5.5	18.7
	16.0	18.4
	17.0	18.3
	18.5	18.0
	19.0	15.0
	24.0	9.5
	27.0	6.3
	28.0	6.0
	37.0	5.3
	49.0	5.0
	53.0	4.7
	97.0	4.6
43°08.7', 87°02.0'		
18	0	19.9
	2.5	19.1
	16.5	18.7
	17.0	18.4
	19.0	17.6
	21.0	9.9
	21.5	9.0
	23.5	7.0
	29.0	5.8
	36.0	5.3
	40.0	5.0
	45.0	4.8
	65.0	4.4
	90.0	4.3
43°08.2', 87°05.1'		
19	0	19.7
	1.5	19.5
	2.0	18.8
	4.5	18.4
	17.0	18.0
	19.5	17.2
	23.0	11.7
	24.5	7.4
	30.0	6.0
	44.0	4.8
	63.0	4.4
	66.0	4.3
	87.0	4.3
43°08.0', 87°07.2'		
20	0	19.8
	2.0	18.7
	6.0	18.1
	11.0	17.8

No.	Corr.	Corr.
20	14.0	17.7
	18.0	17.5
	23.0	14.7
	24.0	10.0
	25.0	8.0
	31.0	5.7
	41.0	4.8
	47.0	4.6
	83.0	4.2
<hr/>		
43°07.7', 87°09.3'		
21	0	19.6
	1.5	18.8
	6.0	17.9
	16.5	17.4
	18.5	16.5
	22.5	7.6
	25.5	5.9
	36.0	4.7
	58.5	4.5
	80.5	4.2
<hr/>		
43°07.2', 87°11.8'		
22	0	19.9
	2.0	19.0
	6.0	18.4
	8.0	17.9
	13.0	17.6
	16.0	16.9
	20.0	13.0
	21.0	8.8
	23.0	7.6
	25.0	6.6
	29.0	5.6
	32.0	5.2
	41.5	4.8
	43.0	4.5
	79.0	4.1
<hr/>		
43°07.0', 87°13.3'		
23	0	20.0
	0.5	19.3
	2.0	19.0
	7.0	18.6
	8.0	18.2
	15.5	17.6
	20.5	10.2
	21.5	9.6
	23.0	7.2
	25.5	6.2
	31.0	5.5
	38.0	5.1
	43.0	4.7
	47.0	4.6
	77.0	4.2
<hr/>		
43°06.7', 87°15.3'		
24	0	20.0
	2.0	19.3
	7.0	18.7
	14.5	18.4
	17.0	17.8

No.	Corr.	Corr.
24	21.0	11.5
	23.5	8.0
	29.0	6.3
	30.0	5.9
	33.0	5.7
	41.0	4.9
	47.0	4.6
	81.0	4.2
<hr/>		
43°06.2', 87°17.4'		
25	0	19.9
	1.5	19.3
	15.5	18.5
	20.5	12.6
	21.0	11.8
	25.5	7.9
	29.0	7.4
	31.0	6.5
	37.5	5.6
	46.5	4.8
	58.5	4.4
	81.5	4.2
<hr/>		
43°05.9', 87°19.4'		
26	0	19.6
	1.5	19.3
	4.5	18.9
	14.5	18.5
	15.5	18.2
	17.5	14.0
	18.5	12.7
	21.0	9.5
	33.5	6.1
	49.5	4.8
	55.5	4.6
	80.5	4.3
<hr/>		
43°05.7', 87°21.6'		
27	0	19.1
	2.5	19.1
	3.0	18.9
	8.0	18.4
	15.0	18.3
	18.0	15.0
	19.0	14.0
	23.0	9.5
	29.0	7.2
	35.0	6.0
	36.0	5.2
	39.0	4.9
	66.5	4.7
<hr/>		
43°05.3', 87°23.6'		
28	0	19.1
	2	19.1
	2.5	18.8
	13.5	18.4
	16.5	14.6
	23.5	7.0
	26.5	5.1
	56.5	4.6

No.	Corr.	Corr.
43°05.2', 87°25.7'		
29	0	18.7
	5.0	18.6
	8.5	18.0
	16.0	17.8
	20.0	9.0
	22.0	7.2
	26.0	5.9
	37.0	4.8
	46.0	4.3
	76.0	3.9
	95.0	3.8
<hr/>		
43°04.5', 87°29.8'		
30	0	19.0
	3.0	19.0
	9.0	18.3
	13.0	18.1
	15.0	17.4
	16.0	16.7
	18.0	8.7
	19.5	7.0
	25.5	5.7
	30.0	5.2
	66.0	4.0
	91.0	3.8
<hr/>		
43°04.0', 87°33.4'		
31	0	19.4
	3.0	19.4
	4.0	18.9
	6.0	18.7
	15.0	18.3
	16.5	13.9
	18.0	11.9
	19.5	7.0
	27.0	5.4
	33.0	4.8
	60.0	3.9
	85.5	3.7
<hr/>		
43°03.6', 87°36.4'		
32	0	19.1
	3.0	19.1
	6.0	19.0
	16.5	18.6
	17.5	17.9
	18.0	11.9
	19.0	8.4
	20.0	7.7
	25.5	6.4
	36.0	5.4
	52.0	4.6
	55.0	4.2
	78.0	4.0
<hr/>		
43°03.2', 87°39.2'		
33	0	19.0
	6.0	19.0
	9.0	18.9
	17.0	18.6
	19.0	9.3

Slide No.	Depth, M Corr.	Temp. °C Corr.
33	21.0	7.2
	24.0	6.6
	31.5	5.9
	53.0	4.7
	60.0	4.6
	63.0	4.3
	69.0	4.1
<hr/>		
43°02.9', 87°42.0'		
34	1.0	18.9
	6.0	18.9
	10.0	18.5
	13.0	18.4
	19.0	18.3
	21.0	17.9
	22.0	16.6
	23.0	10.6
	24.0	8.2
	29.0	6.6
	37.0	5.8
	39.0	5.7
	43.0	5.1
	57.0	4.7
<hr/>		
43°02.4', 87°44.8'		
35	0	20.1
	7.5	20.0
	9.5	19.7
	24.0	18.9
	25.0	18.5
	26.5	10.5
	28.0	8.0
	29.5	7.5
	30.5	6.8
	32.5	6.0
	45.0	5.7
<hr/>		
43°02.1', 87°47.6'		
36	1.0	20.5
	9.0	20.5
	11.0	20.4
	11.5	19.9
	12.5	19.8
	17.0	19.6
	21.0	19.4
	22.5	19.2
	23.0	18.9
	27.0	18.6
<hr/>		
43°01.8', 87°50.0'		
37	0	20.6
	5.5	20.6
	6.5	20.4
	18.0	20.3

Slide No.	Depth, M Corr.	Temp. °C Corr.
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Slide No.	Depth, M Corr.	Temp. °C Corr.
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Grand Haven to Milwaukee
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Slide No.	Depth, M	Temp. °C
43°03.4', 86°18.0'		
141	0	19.3
	10	19.3
	14	19.1
	15	18.5
	18	18.4
	19	18.1
	20	18.1
	22	17.5
	23	16.6
	25	16.3
	27	16.2
43°03.2', 86°19.8'		
142	0	18.7
	15	18.7
	16	18.3
	17	17.1
	21	16.8
	24	15.1
	25	14.0
	29	11.8
	30	10.3
	33	9.1
	37	8.9
	41	8.0
	43	6.3
	45	5.7
43°02.9', 86°22.3'		
143	0	18.1
	14	18.0
	16.2	17.8
	17	15.7
	20	14.4
	21	13.7
	22.5	13.0
	23	11.0
	28	7.9
	32	6.2
	39	4.7
	54	4.5
	60	4.5
	65	4.3
43°02.8', 86°24.5'		
144	0	18.6
	7	18.6
	13	17.9
	15	17.8
	18	16.8
	20	13.6
	21	12.6
	22	10.6
	23	10.0
	25	7.8
	28	6.2
	31	5.3
	36	4.8

Slide No.	Depth, M	Temp. °C
43°02.7', 86°26.8'		
145	0	18.8
	7	18.7
	10	18.4
	16	15.4
	18	13.0
	19	12.2
	22	11.9
	27	6.2
	32	5.1
	37	4.8
	40	4.4
	58	4.2
43°02.6', 86°29.0'		
146	0	18.9
	11	18.7
	12	18.4
	16	12.2
	21	6.9
	24	5.4
	34	4.7
	44	4.2
	59	4.2
43°02.5', 86°31.3'		
147	0	19.0
	13	18.8
	15	18.5
	16	15.3
	18	8.8
	21	6.9
	27	5.7
	32	5.3
	36	4.6
	40	4.4
	60	4.3
43°02.4', 86°33.5'		
148	0	19.0
	13	18.8
	16	18.2
	17	17.2
	20	7.7
	21	6.7
	27	5.5
	29	5.1
	39	4.3
	44	4.2
	60	4.2
	67	4.2
43°02.2', 86°35.8'		
149	0	19.1
	12	19.1
	15	18.8
	19	17.8

Slide No.	Depth, M	Temp. °C
43°02.1', 86°38.2'		
149	21	16.3
	22	11.3
	23	7.8
	27	5.8
	29	5.3
	31	4.8
	36	4.5
	45	4.4
43°02.0', 86°38.2'		
150	0	19.3
	16	19.2
	17	19.0
	20	18.4
	22	18.0
	23	12.4
	25	7.2
	27	6.2
	30	5.8
	37	4.7
	60	4.4
	85	4.4
43°01.9', 86°40.5'		
151	0	19.2
	10	19.1
	14	19.0
	18	18.4
	21	18.2
	22	14.3
	24	6.8
	27	5.6
	30	5.4
	33	4.9
	46	4.5
	60	4.5
	69	4.5
43°01.8', 86°42.7'		
152	0	19.2
	10	19.1
	14	19.0
	17	18.6
	19	18.3
	22	17.8
	23	9.3
	26	6.5
	27	6.3
	30	5.6
	32	5.5
	39	4.6
	60	4.4
	76	4.3
	86	4.4
43°01.7', 86°44.9'		
153	0	19.2
	9	19.2
	12	19.1
	15	18.9

Slide No.	Depth, M Corr.	Temp. °C Corr.
153	18	18.4
	22	17.7
	23	12.4
	27	9.4
	28	7.4
	30	6.4
	36	5.3
	42	4.7
	45	4.6
	60	4.4
	96	4.3
<hr/>		
	43°01.6', 86°47.4'	
154	0	19.3
	13	19.3
	16	19.2
	18	19.0
	20	18.6
	23	18.1
	25	12.4
	26	9.4
	28	6.9
	29	6.2
	35	5.6
	36	5.3
	43	4.6
	60	4.5
	88	4.4
<hr/>		
	43°01.5', 86°49.5'	
155	0	19.3
	16	19.1
	17	18.6
	20	18.3
	22	17.4
	24	11.4
	27	7.2
	34	5.6
	37	5.5
	38	5.0
	39	4.7
	49	4.6
	60	4.4
	78	4.4
<hr/>		
	43°01.4', 86°51.8'	
156	0	19.3
	9	19.2
	15	19.0
	17	18.5
	20	18.1
	22	17.3
	24	13.3
	25	11.8
	26	8.8
	28	7.3
	31	6.2
	32	4.8
	39	4.4
	51	4.4
	60	4.3
	78	4.3

Slide No.	Depth, M Corr.	Temp. °C Corr.
	43°01.3', 86°53.9'	
157	0	19.3
	7	19.3
	16	19.2
	19	18.4
	23	17.5
	25	13.3
	28	8.3
	30	6.3
	33	5.4
	34	4.9
	37	4.6
	60	4.3
	86	4.2
<hr/>		
	43°01.1', 86°56.3'	
158	0	19.3
	12	19.2
	15	19.1
	17	18.7
	23	15.9
	26	10.4
	29	6.6
	30	6.2
	33	5.4
	35	4.6
	42	4.5
	60	4.5
	67	4.5
<hr/>		
	43°01.0', 86°58.5'	
159	0	19.3
	10	19.3
	14	19.2
	18	18.5
	21	17.8
	25	13.4
	27	9.4
	29	7.2
	30	6.4
	32	5.7
	33	5.0
	36	4.7
	60	4.6
	84	4.6
<hr/>		
	43°00.8', 87°00.8'	
160	0	19.4
	5	19.4
	8	19.2
	14	18.9
	15	18.6
	17	18.4
	18	18.0
	23	16.8
	25	14.3
	26	10.3
	27	8.8
	28	8.0
	30	5.1
	46	4.5
	60	4.5

Slide No.	Depth, M Corr.	Temp. °C Corr.
	43°00.6', 87°03.0'	
160	82	4.5
<hr/>		
	43°00.6', 87°03.0'	
161	0	19.6
	7	19.5
	13	19.3
	15	18.6
	19	18.1
	23	16.9
	25	13.8
	27	7.5
	31	5.3
	33	4.9
	60	4.6
	78	4.6
<hr/>		
	43°00.4', 87°05.5'	
162	0	19.8
	4	19.6
	9	19.6
	15	19.0
	16	18.6
	21	18.0
	24	16.6
	27	12.3
	28	7.1
	31	6.1
	33	5.4
	35	4.7
	44	4.5
	60	4.5
	76	4.4
<hr/>		
	43°00.3', 87°07.6'	
163	0	20.0
	10	19.9
	13	19.6
	17	19.2
	19	18.7
	25	16.3
	30	6.8
	33	6.4
	35	5.2
	43	5.0
	60	4.7
	78	4.6
<hr/>		
	43°00.2', 87°09.8'	
164	0	20.0
	3	19.8
	7	19.8
	13	19.4
	19	18.9
	22	16.5
	25	14.5
	27	9.6
	29	7.8
	32	5.4
	35	5.1
	40	4.9
	60	4.6
	79	4.5

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°00.0', 87°12.1'		
165	0	20.1
	2	20.0
	3	19.9
	12	19.7
	17	18.9
	20	15.7
	25	11.2
	27	6.3
	34	5.1
	60	4.5
	80	4.4
<hr/> 42°59.9', 87°14.5'		
166	0	19.9
	3	19.5
	15	19.2
	16	19.0
	17.5	18.6
	19	16.7
	22	11.8
	24	9.7
	26	7.0
	28	6.8
	29	5.2
	32	4.5
	60	4.1
	84	4.0
<hr/> 42°59.7', 87°16.7'		
167	0	19.7
	3	19.3
	11	19.1
	18	17.7
	22.5	9.0
	24	7.8
	24.5	5.5
	31	4.8
	60	4.6
	78	4.3
<hr/> 42°59.5', 87°19.0'		
168	0	19.7
	5	19.4
	12	19.2
	16.5	18.6
	17	18.1
	21	9.9
	23	8.5
	25	7.9
	27.5	5.4
	30	5.1
	33	4.9
	36	4.6
	60	4.4
	72	4.4
<hr/> 42°59.3', 87°21.2'		
169	0	19.9
	3	19.4
	6	19.3
	12	19.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 169		
	17	18.3
	19.5	14.0
	22.5	9.6
	29	5.3
	48	4.4
	60	4.3
	84	4.2
<hr/> 42°59.2', 87°23.4'		
170	0	19.9
	2	19.4
	6	19.3
	12	19.0
	18	18.2
	18.5	17.5
	20	13.8
	23	9.4
	26	8.5
	27	8.0
	28	6.9
	31	5.4
	33	5.1
	39	4.8
	60	4.5
	79	4.4
<hr/> 42°59.0', 87°25.8'		
171	0	20.0
	6	19.4
	10	19.0
	13	18.7
	16	18.5
	19	18.1
	20	17.8
	21.5	17.3
	22	11.8
	25	8.1
	31	5.7
	37	4.8
	43	4.3
	49	4.1
	60	4.0
	85	3.9
<hr/> 42°58.9', 87°28.1'		
172	0	20.3
	2	19.8
	4	19.6
	7	19.5
	10	19.3
	15	18.8
	16	18.5
	19	18.3
	23	9.5
	24	8.1
	27	6.0
	31	5.0
	34	4.8
	43	4.6
	55	4.1
	60	4.0
	83	3.9

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 42°58.7', 87°30.3'		
173	0	20.4
	1	20.0
	7	19.8
	13	19.5
	19	19.0
	21	17.3
	23	10.1
	26.5	6.1
	34	5.0
	40	4.7
	46	4.6
	60	4.2
	86	4.1
<hr/> 42°58.6', 87°32.7'		
174	0	20.3
	3	19.8
	9	19.7
	14	18.8
	18	18.4
	19.5	18.2
	21	14
	24	8.5
	27	7.0
	36	6.0
	44	5.1
	46	4.3
	60	4.2
	75	4.1
<hr/> 42°58.5', 87°35.1'		
175	0	20.6
	0.5	20.0
	2	19.5
	10	19.4
	13	19.2
	16	18.7
	20	18.1
	23	10.8
	25	7.8
	28	6.7
	37	5.2
	43	4.8
	46	4.6
	60	4.5
	62	4.5
<hr/> 42°58.3', 87°37.2'		
176	0	20.6
	1	19.8
	3	19.5
	6	19.5
	8	19.3
	10	19.2
	18	18.8
	20	18.1
	22	14.6
	25	7.0
	27	6.4
	36	5.3

Slide No.	Depth, M Corr.	Temp. °C Corr.
176	39 48	4.7 4.5
<hr/>		
	42°58.2', 87°39.5'	
177	0	20.7
	1	20.1
	2	20.0
	9	19.9
	21	18.7
	22.5	13.6
	24	8.6
	26	7.1
	31	5.8
	34	5.1
	42	4.8
<hr/>		
	42°58.1', 87°41.7'	
178	0	20.7
	2	20.1
	15	19.6
	19.5	18.4
	22	9.6
	23	6.4
	24	5.8
	33	5.4
<hr/>		
	42°57.9', 87°44.0'	
179	0	20.8
	1	20.6
	2	20.3
	15	19.7
	19	14.7
	20	10.2
	21.5	7.2
	23	6.7
	26	6.7
<hr/>		
	42°57.7', 87°46.3'	
180	0	20.9
	2	20.4
	4	20.1
	12	19.7
	15	18.7
	16	16.7
	18	13.5
	20	7.9
	22	7.5
	23	7.4

Slide No.	Depth, M Corr.	Temp. °C Corr.
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Slide No.	Depth, M Corr.	Temp. °C Corr.
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Grand Haven to Milwaukee
3 November 1962

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	
<hr/> 43°03.5', 86°18.0'		
305	0	12.8
	2	12.8
	16	12.8
<hr/> 43°03.4', 86°20.4'		
306	0	13.0
	2	13.0
	25	13.0
	26	12.7
	35	12.5
	37	12.1
	41	12.1
<hr/> 43°03.3', 86°22.8'		
307	0	12.8
	2	12.8
	26	12.8
	32	12.7
	40	11.7
	43	11.4
	45	10.9
	49	10.6
	50	10.1
	53	9.6
	56	8.1
	58.5	6.3
	64	6.0
	69	4.3
<hr/> 43°03.4', 86°25.1'		
308	0	12.3
	4	12.3
	19	12.2
	25	12.1
	26	12.0
	37	11.7
	42	9.8
	44.5	9.1
	45	8.0
	48	7.6
	55	4.5
	72	4.3
<hr/> 43°03.3', 86°27.5'		
309	0	12.4
	3	12.4
	18	12.3
	23	12.1
	30	12.0
	33	11.4
	35	10.3
	37	7.3
	40	5.2
	46	4.7
	49	4.7
	74	4.6

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	
<hr/> 43°03.3', 86°29.8'		
310	0	12.5
	4	12.5
	19	12.4
	33	12.0
	35	11.3
	38	6.9
	39	6.4
	41	5.4
	44	5.1
	79	4.9
<hr/> 43°03.2', 86°32.3'		
311	0	12.5
	1	12.5
	11	12.5
	16	12.2
	21	12.2
	23	12.0
	27	11.7
	31	9.0
	38	8.0
	41	7.2
	42	6.0
	46	5.5
	53	5.0
	57	4.3
	80	4.0
<hr/> 43°03.2', 86°34.7'		
312	0	12.2
	4	12.2
	22	12.2
	27	12.0
	32	9.3
	37	9.1
	44	8.4
	49	7.4
<hr/> 43°03.1', 86°37.1'		
313	0	11.8
	4	11.8
	11	11.8
	17	11.5
	22	11.0
	26	10.5
	30	9.7
	38	9.3
	42	8.5
	47	4.9
	51	4.7
	55	4.2
	67	3.9
	84	3.8
<hr/> 43°03.1', 86°39.4'		
314	0	10.7
	4	10.7
	8	10.7

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	
<hr/> 43°03.0', 86°41.7'		
314	16	10.2
	25	10.0
	31	9.6
	38	9.5
	40	9.2
	41	6.4
	44	5.4
	47	5.2
	52	4.7
	89	4.5
<hr/> 43°03.0', 86°41.7'		
315	0	10.8
	4	10.8
	21	10.7
	26	10.5
	32	10.4
	41	9.5
	44	6.2
	47	5.2
	81	4.5
	99	4.5
<hr/> 43°03.0', 86°44.1'		
316	0	10.6
	4	10.6
	41	10.5
	42	8.2
	46	5.1
	48	4.5
	105	4.2
<hr/> 43°03.0', 86°46.5'		
317	0	10.6
	4	10.6
	22	10.6
	37	10.4
	46	8.6
	54	7.4
	57	5.6
	61	5.2
	77	4.6
	101	4.5
<hr/> 43°02.9', 86°48.9'		
318	0	10.3
	4	10.3
	22	10.3
	34	10.2
	39	9.9
	45	8.1
	52	7.5
	61	7.0
	66	6.2
	68	5.2
	69	5.0
	84	4.7
	99	4.7

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°02.9', 86°51.3'		
319	0	10.5
	4	10.5
	22	10.5
	30	10.2
	33	9.8
	37	8.9
	47	8.3
	50	7.6
	52	7.4
	63	5.2
	96	5.0
<hr/> 43°02.9', 86°53.6'		
320	0	10.2
	4	10.2
	12	10.2
	14	9.8
	23	9.6
	29	8.8
	35	8.3
	38	7.4
	45	6.3
	54	6.0
	56	5.5
	59	5.0
	79	4.6
	94	4.5
<hr/> 43°02.8', 86°56.0'		
321	0	10.3
	4	10.3
	13	10.2
	16	10.0
	38	9.5
	42	8.6
	43	7.6
	47	7.4
	56	4.6
	92	4.4
<hr/> 43°02.8', 86°58.2'		
322	0	9.8
	4	9.8
	22	9.8
	33	9.6
	43	8.1
	47	7.0
	51	6.1
	53	5.4
	85	5.1
<hr/> 43°02.7', 87°00.8'		
323	0	10.1
	4	10.1
	31	10.1
	35	9.8
	39	9.3
	41	8.1
	43	5.6
	46	5.0
	81	4.6

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°02.7', 87°03.2'		
324	0	10.0
	4	10.0
	26	9.9
	30	9.6
	31	9.4
	36	7.9
	41	4.8
	79	4.4
<hr/> 43°02.7', 87°05.5'		
325	0	10.1
	4	10.1
	31	10.0
	33	8.6
	35	6.0
	38	4.9
	40	4.8
	75	4.6
<hr/> 43°02.6', 87°07.7'		
326	0	9.9
	4	9.9
	16	9.9
	41	9.6
	45	7.1
	48	6.1
	51	5.2
	76	5.1
<hr/> 43°02.6', 87°10.2'		
327	0	9.9
	4	9.9
	19	9.9
	28	9.6
	34	9.5
	38	9.3
	41	7.7
	42.5	6.0
	43.5	5.5
	46	5.0
	78	4.8
<hr/> 43°02.5', 87°12.7'		
328	0	10.0
	1	10.0
	15	10.1
	22	10.0
	26	9.8
	32	9.6
	37	9.2
	40	8.9
	41	6.8
	46	4.9
	78	4.5
<hr/> 43°02.5', 87°15.1'		
329	0	9.9
	4	9.9
	13	9.8
	23	9.6
	29	9.2
	41	8.5
	42	8.1

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 329		
	46	7.9
	50	5.9
	54	5.0
	78	4.6
<hr/> 43°02.4', 87°17.3'		
330	0	9.7
	4	9.7
	30	9.6
	32	9.2
	34	8.6
	35	8.5
	38	6.8
	40	6.2
	42	5.2
	48	4.8
	79	4.8
<hr/> 43°02.4', 87°19.7'		
331	0	9.8
	5	9.8
	25	9.8
	36	9.7
	40	9.3
	43	8.3
	50	5.8
	57	5.3
	73	5.1
<hr/> 43°02.4', 87°22.1'		
332	0	10.1
	5	10.1
	14	10.1
	42	9.7
	50	8.0
	53	7.6
	54	6.8
	58	5.8
	60	5.3
<hr/> 43°02.3', 87°24.5'		
333	0	10.1
	+1.5	10.1
	25.5	10.1
	43.5	10.0
	45.5	9.6
	46.5	8.0
	48.5	7.4
	50.5	6.7
	58.5	6.3
<hr/> 43°02.3', 87°26.8'		
334	0	10.0
	4	10.0
	22	10.0
	40	9.8
	43	9.7
	47	9.1
	50	8.7
	51	8.1
	56	7.3
	58	6.2
	60	5.2
	95	4.8

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	
<hr/> 43°02.3', 87°29.3'		
335	0	10.0
	4	10.0
	16	10.0
	30	9.7
	44	9.5
	47	9.4
	56	9.2
	59	6.7
	62	6.1
	65	5.0
	68	4.9
	92	4.6
<hr/> 43°02.2', 87°31.6'		
336	0	10.5
	4	10.5
	16	10.6
	28	10.5
	43	10.2
	58	9.6
	60	7.7
	63	6.8
	66	6.1
	82	5.7
	86	5.7
<hr/> 43°02.2', 87°34.0'		
337	0	11.0
	5	11.0
	20	11.0
	26	10.8
	36	10.7
	43	10.2
	48	9.9
	52	8.7
	57	6.7
	70	5.4
	81	5.4
<hr/> 43°02.1', 87°36.5'		
338	0	10.9
	6	10.8
	24	10.7
	36	10.4
	47	10.3
	53	10.0
	59	8.0
	65	6.1
	77	5.7
<hr/> 43°02.0', 87°39.0'		
339	0	10.8
	1	10.8
	19	10.8
	23	10.7
	27	10.6
	43	10.4
	64	10.4
	70	10.1

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	
<hr/> 43°01.9', 87°41.1'		
340	0	11.0
	1	11.0
	52	11.0
	54	10.8
	59	10.8
<hr/> 43°01.8', 87°43.4'		
341	0	11.1
	1	11.1
	43	11.0
	49	11.0
<hr/> 43°01.7', 87°45.8'		
342	0	11.2
	1	11.2
	33	11.2
<hr/> 43°01.7', 87°48.1'		
343	0	11.0
	1	11.0
	21.5	11.0
<hr/> 43°01.6', 87°50.5'		
344	0	10.7
	1	10.7
	15.5	10.7

Slide No.	Depth, M	Temp. °C
Corr.	Corr.	

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Slide No.	Depth, M Corr.	Temp. °C Corr.
42°44.1', 87°43.3'		
396	0	8.7
	12.5	8.7
42°44.6', 87°41.0'		
397	0	10.1
	18.5	10.1
42°45.1', 87°38.6'		
398	0	10.0
	23	10.0
42°45.6', 87°36.0'		
399	0	9.9
	31	9.9
42°46.1', 87°33.8'		
400	0	9.5
	49	9.5
42°46.6', 87°31.6'		
401	0	9.2
	57.5	9.2
	58.5	9.1
	60	9.0
	68.5	8.7
42°47.1', 87°29.2'		
402	0	9.1
	48	9.0
	50	8.9
	52	8.6
	54	7.9
	59	7.0
	60	6.6
	62	6.1
	64	5.9
	66	5.2
	80	4.8
42°47.6', 87°27.2'		
403	0	8.9
	36	8.9
	45	8.8
	55	8.5
	60	5.2
	61	4.8
	63	4.6
	89	4.4
42°48.0', 87°24.9'		
404	0	8.8
	49	8.7
	51	8.4
	53	8.0
	55	7.1
	62	6.1
	63	5.7
	69	5.0
	99	4.4

Slide No.	Depth, M Corr.	Temp. °C Corr.
42°48.5', 87°23.0'		
405	0	8.8
	24	8.9
	39	8.9
	48	8.7
	50	8.1
	55	7.2
	56	6.6
	58	6.4
	59	6.1
	60	6.0
	63	5.7
	72	5.5
	78	5.2
	90	4.9
	101	4.7
42°49.0', 87°20.9'		
406	0	8.4
	45	8.4
	49	8.3
	51	8.0
	54	7.4
	60	5.5
	63	4.9
	81	4.4
	96	4.4
42°49.5', 87°18.7'		
407	0	8.3
	47	8.2
	50	7.1
	55	6.4
	56	6.0
	60	5.3
	67	4.4
	81	4.2
	109	4.1
42°49.9', 87°16.7'		
408	0	8.4
	45	8.4
	46	8.1
	48	7.0
	52	6.3
	60	5.3
	67	4.4
	116	4.3
42°50.5', 87°14.5'		
409	0	8.2
	46	8.1
	48	7.8
	50	7.1
	53	5.4
	54	5.3
	60	4.6
	67	4.2
	121	4.1

Slide No.	Depth, M Corr.	Temp. °C Corr.
42°50.9', 87°12.3'		
410	0	8.6
	39	8.5
	44	8.4
	45	8.2
	48	5.8
	52	4.5
	60	4.2
	72	4.0
	133	4.0
42°51.4', 87°10.2'		
411	0	8.7
	36	8.7
	48	8.6
	51	6.4
	53	5.3
	60	4.6
	66	4.5
	135	4.4
42°51.8', 87°08.0'		
412	0	8.8
	21	8.8
	49	8.6
	51	7.5
	60	5.4
	64	4.7
	81	4.5
	135	4.5
42°52.3', 87°06.0'		
413	0	9.0
	21	9.0
	36	8.8
	42	8.7
	44	8.6
	48	8.4
	51	8.3
	52	8.2
	58	6.4
	60	6.3
	61	6.2
	63	5.6
	68	4.8
	72	4.6
	75	4.4
	81	4.3
	130	4.1
42°52.8', 87°04.0'		
414	0	9.0
	51	9.0
	56	8.8
	60	6.6
	61	6.3
	62	5.9
	64	5.0
	66	4.7

Slide No.	Depth, M Corr.	Temp. °C Corr.
414	81	4.5
	123	4.3
42°53.0', 87°01.8'		
415	0	9.1
	18	9.1
	30	8.8
	42	8.5
	54	8.3
	57	6.2
	59	5.2
	60	5.1
	64	4.5
	81	4.4
	119	4.2
42°53.5', 86°59.6'		
416	0	9.2
	35	9.2
	39	9.0
	40	8.7
	44	6.1
	47	4.9
	53	4.6
	60	4.5
	115	4.1
42°54.0', 86°57.2'		
417	0	9.3
	38	9.2
	40	9.1
	41	8.9
	43	6.7
	47	4.7
	50	4.5
	60	4.4
	95	4.2
	110	4.2
42°54.6', 86°55.0'		
418	0	9.6
	42.5	9.6
	43.5	9.0
	45	8.4
	49	5.5
	51	4.9
	54	4.7
	57	4.6
	60	4.6
	66	4.5
	81	4.4
	106	4.4
42°55.1', 86°52.9'		
419	0	9.5
	42	9.5
	48	9.4
	49.5	8.2
	51	7.5
	55	5.5
	57	4.9
	60	4.8
	66	4.7

Slide No.	Depth, M Corr.	Temp. °C Corr.
419	81	4.6
	101	4.6
42°55.4', 86°50.5'		
420	0	9.5
	48	9.5
	54	9.3
	55	8.7
	56	7.9
	57	7.5
	59	5.7
	60	5.6
	63	5.5
	78	5.4
	84	5.3
	87	5.2
	93	4.9
	96	4.8
	99	4.8
42°55.9', 86°48.2'		
421	0	9.3
	45	9.2
	51	9.0
	54	7.9
	56	7.0
	60	6.6
	65	6.1
	67	5.2
	81	5.1
	96	4.9
42°56.3', 86°46.1'		
422	0	9.3
	18	9.2
	27	9.0
	45	9.0
	48	8.9
	51	8.4
	53	7.3
	58	5.9
	60	5.7
	63	5.4
	66	4.7
	75	4.5
	81	4.4
	96	4.4
42°56.8', 86°43.7'		
423	0	10.4
	5	10.4
	11	10.3
	14	10.2
	16	10.1
	20	9.5
	23	9.3
	47	9.2
	51.5	9.1
	53	7.9
	55	6.7
	60	5.9
	62	5.3

Slide No.	Depth, M Corr.	Temp. °C Corr.
423	65	4.7
	71	4.5
	80	4.4
	96	4.4
42°57.3', 86°41.5'		
424	0	10.9
	17	10.8
	21.5	10.5
	23	10.0
	26	9.4
	29	9.2
	50	9.1
	54	8.8
	55	8.2
	57	8.0
	59	6.1
	60	6.0
	63	5.5
	65	5.2
	71	4.7
	77	4.6
	95	4.5
42°57.8', 86°39.2'		
425	0	11.4
	20	11.4
	22	11.3
	24	10.5
	25	10.3
	27	9.6
	29	9.4
	32	9.3
	50	9.2
	52	9.1
	55.5	7.4
	57	6.2
	60	5.9
	63	5.1
	65	5.0
	77	4.9
	91	4.9
42°58.2', 86°37.0'		
426	0	11.1
	27.5	11.2
	29.5	11.1
	36.5	10.7
	37.5	10.4
	40.5	8.2
	42.5	7.5
	44.5	6.2
	46.5	5.7
	50.5	5.5
	56.5	5.4
	60	5.4
	74.5	5.3
	83.5	5.0
	88.5	5.0
42°58.8', 86°34.1'		
427	0	11.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
427	9	11.0
	12	10.9
	18	10.6
	36	10.5
	38	7.6
	40	7.1
	41	5.7
	42	5.5
	45	5.2
	51	5.0
	60	4.9
	86	4.8

42°59.6', 86°31.1'

428	0	11.1
	27	11.0
	33	10.8
	36	10.7
	41	10.6
	42	10.5
	44	10.4
	46	7.2
	48	5.5
	50	5.2
	54	5.1
	60	5.0
	82	4.9

43°00.3', 86°28.2'

429	0	11.0
	41	11.0
	42	10.9
	43	10.7
	44	10.4
	45	9.9
	47	9.6
	48	6.6
	49	5.7
	50	5.3
	51	5.2
	59	5.0
	60	5.0
	80	5.0

43°00.8', 86°25.4'

430	0	12.1
	11	12.0
	20	11.9
	26	11.7
	41	11.7
	47	11.5
	52	11.3
	60	8.3
	62	7.7
	65	6.4
	68	6.0
	72	6.0

43°01.3', 86°22.6'

431	0	12.8
	42	12.7
	50	12.2

Slide No.	Depth, M Corr.	Temp. °C Corr.
431	56	11.6
	58	10.9
	60	10.9
	62	10.9

43°01.8', 86°19.7'

432	0	11.5
	38.5	11.5

43°02.5', 86°16.8'

433	0	11.3
	28.5	11.3

Slide No.	Depth, M Corr.	Temp. °C Corr.
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Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°03.1', 86°17.7'		
434	0	1.0
	16	1.1
	25	1.4
<hr/> 43°03.1', 86°20.6'		
435	0	1.0
	46	1.2
	51	1.6
<hr/> 43°03.1', 86°22.8'		
436	0	1.0
	60	1.0
	75	1.0
<hr/> 43°03.1', 86°25.3'		
437	0	1.0
	60	1.0
	67	1.0
<hr/> 43°03.0', 86°27.8'		
438	0	0.8
	60	0.8
	82	0.8
<hr/> 43°03.0', 86°29.9'		
439	0	1.0
	60	1.0
	94	1.0
<hr/> 43°03.0', 86°32.0'		
440	0	1.0
	60	0.9
	100	0.9
<hr/> 43°03.0', 86°34.5'		
441	0	1.3
	60	1.3
	103	1.2
<hr/> 43°02.9', 86°36.7'		
442	0	1.3
	60	1.2
	99	1.2
<hr/> 43°02.9', 86°39.1'		
443	0	1.3
	60	1.3
	107	1.3
<hr/> 43°02.9', 86°41.4'		
444	0	1.3
	60	1.2
	108	1.2
<hr/> 43°02.9', 86°43.7'		
445	0	1.3
	60	1.2
	65	1.2
	101	1.1
<hr/> 43°02.8', 86°46.0'		
446	0	1.2
	35	1.2
	60	1.1
	92	1.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°02.8', 86°48.4'		
447	0	1.2
	50	1.2
	60	1.2
	97	1.0
<hr/> 43°02.8', 86°50.9'		
448	0	1.3
	59	1.3
	60	1.3
	93	1.1
<hr/> 43°02.8', 86°53.0'		
449	0	1.3
	40	1.3
	60	1.2
	94	1.1
<hr/> 43°02.7', 86°55.6'		
450	0	1.3
	60	1.3
	89	1.3
<hr/> 43°02.6', 86°57.8'		
451	0	1.2
	60	1.1
	89	1.1
<hr/> 43°02.6', 87°00.1'		
452	0	1.2
	60	1.1
	72	1.1
<hr/> 43°02.6', 87°02.7'		
453	0	1.1
	78	1.0
<hr/> 43°02.5', 87°04.8'		
454	0	1.1
	77	1.0
<hr/> 43°02.5', 87°07.1'		
455	0	1.1
	75	1.1
<hr/> 43°02.4', 87°09.3'		
456	0	1.1
	70	0.9
<hr/> 43°02.4', 87°11.6'		
457	0	1.1
	71	1.0
<hr/> 43°02.4', 87°13.8'		
458	0	1.1
	85	0.8
<hr/> 43°02.3', 87°16.0'		
459	0	1.1
	87	0.9
<hr/> 43°02.2', 87°18.2'		
460	0	1.1
	87	0.9
<hr/> 43°02.2', 87°20.5'		
461	0	1.1
	57	1.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°02.2', 87°22.7'		
462	0	1.1
	91	0.9
<hr/> 43°02.1', 87°25.0'		
463	0	1.5
	89	1.3
<hr/> 43°02.1', 87°27.2'		
464	0	1.6
	92	1.3
<hr/> 43°02.1', 87°29.8'		
465	0	1.6
	88	1.3
<hr/> 43°02.1', 87°32.1'		
466	0	1.6
	74	1.4
<hr/> 43°02.0', 87°34.6'		
467	0	1.6
	76	1.3
<hr/> 43°02.0', 87°37.7'		
468	0	1.6
	68	1.4
<hr/> 43°01.9', 87°40.7'		
469	0	1.8
	56	1.7
<hr/> 43°01.8', 87°42.9'		
470	0	2.0
	44	2.0
<hr/> 43°01.8', 87°46.0'		
471	0	2.4
	34	2.4
<hr/> 43°01.7', 87°48.9'		
472	0	2.4
	20	2.4

Grand Haven to Milwaukee
20 May 1963

Slide No.	Depth, M Corr.	Temp. °C Corr.
43°03.4', 86°16.6'		
575	0	9.0
	13	9.0
	17	8.7
43°03.4', 86°19.1'		
576	0	9.0
	19	8.3
	26	6.0
	30	6.0
43°03.4', 86°21.7'		
577	0	6.5
	28	6.1
	31	5.6
	38	5.6
	41	5.1
	51	4.9
43°03.4', 86°24.0'		
578	0	5.1
	30	4.7
	60	4.3
	75	4.3
One cast missed.		
43°03.3', 86°29.4'		
579	0	3.8
	40	4.0
	60	3.9
	74	3.7
	89	3.9
43°03.2', 86°31.8'		
580	0	3.5
	25	3.5
	60	3.2
	80	3.0
	95	3.2
43°03.2', 86°34.4'		
581	0	3.5
	30	3.5
	60	3.3
	75	3.1
	97	3.0
43°03.2', 86°37.0'		
582	0	3.5
	30	3.5
	60	3.4
	72	3.1
	85	3.5
	100	4.0
43°03.1', 86°39.5'		
583	0	3.2
	47	3.1
	60	3.0
	75	3.0
	97	3.2

Slide No.	Depth, M Corr.	Temp. °C Corr.
43°03.1', 86°42.0'		
584	0	3.0
	32	3.0
	60	2.9
	102	2.8
43°03.0', 86°44.5'		
585	0	3.0
	35	3.0
	60	2.9
	102	2.7
43°03.0', 86°47.2'		
586	0	3.0
	45	3.0
	60	2.9
	99	2.8
43°03.0', 86°49.8'		
587	0	3.0
	60	3.0
	95	2.9
42°02.9', 86°52.3'		
588	0	3.1
	60	3.1
	97	3.0
43°02.9', 86°54.8'		
589	0	3.1
	50	3.1
	60	3.0
	90	3.0
43°02.8', 86°57.4'		
590	0	3.4
	50	3.4
	60	3.3
	84	3.2
43°02.8', 86°59.9'		
591	0	3.6
	50	3.6
	60	3.4
	85	3.3
43°02.7', 87°02.4'		
592	0	3.8
	23	3.8
	60	3.6
	75	3.5
43°02.7', 87°04.9'		
593	0	3.7
	30	3.7
	60	3.6
	68	3.6
43°02.7', 87°07.5'		
594	0	3.7
	30	3.7
	60	3.5
	69	3.5

Slide No.	Depth, M Corr.	Temp. °C Corr.
43°02.6', 87°09.9'		
595	0	3.5
	60	3.2
	81	3.1
43°02.6', 87°12.5'		
596	0	3.7
	30	3.7
	60	3.6
	79	3.5
43°02.5', 87°15.2'		
597	0	3.5
	40	3.5
	60	3.3
	83	3.3
43°02.5', 87°17.7'		
598	0	3.7
	30	3.7
	60	3.5
	80	3.4
43°02.4', 87°20.2'		
599	0	3.5
	30	3.5
	60	3.4
	70	3.4
43°02.4', 87°22.6'		
600	0	3.5
	30	3.5
	53	3.4
43°02.4', 87°25.1'		
601	0	3.5
	25	3.5
	60	3.2
	74	3.2
43°02.3', 87°27.7'		
602	0	3.8
	30	3.7
	60	3.3
	85	3.2
43°02.3', 87°30.2'		
603	0	3.8
	45	3.8
	60	3.7
	79	3.6
43°02.2', 87°32.8'		
604	0	3.8
	30	3.8
	60	3.7
	75	3.6
43°02.2', 87°35.4'		
605	0	3.9
	30	3.9
	60	3.8
	78	3.7

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/>		
43°02.1', 87°38.0'		
606	0	4.0
	60	3.7
	63	3.7
<hr/>		
43°02.1', 87°40.6'		
607	0	4.0
	50	3.8
	60	3.7
<hr/>		
43°02.0', 87°43.0'		
608	0	4.1
	25	4.1
	52	4.0
<hr/>		
43°01.9', 87°45.6'		
609	0	4.7
	35	4.6
<hr/>		
43°01.8', 87°47.9'		
610	0	6.0
	19	6.0
<hr/>		
43°01.7', 87°50.2'		
611	0	8.3
	7	8.0
	9	7.2
	11	7.1
<hr/>		

Slide No.	Depth, M Corr.	Temp. °C Corr.
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Slide No.	Depth, M Corr.	Temp. °C Corr.
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Grand Haven to Port Washington
24 June 1963

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°03.4', 86°16.7'		
624	0	10.6
	3	10.5
	4	9.4
	6	6.9
	7	6.4
	9	5.8
	16	5.8
<hr/> 43°03.4', 86°19.3'		
625	0	10.5
	2	10.3
	3	8.7
	4	8.3
	6	8.1
	9	7.2
	11	6.2
	12	5.6
	13	5.3
	14	5.2
	15	4.8
	20	4.6
	31	4.6
<hr/> 43°03.4', 86°21.9'		
626	0	9.5
	2	9.4
	6	8.7
	8	8.5
	9	8.0
	10	7.8
	12	6.9
	15	6.5
	25	6.0
	27	5.6
	30	5.5
<hr/> 43°03.4', 86°24.3'		
627	0	10.3
	2	10.3
	4	9.2
	6	8.5
	7	8.2
	15	7.6
	16	7.4
	26	6.6
	32	5.2
	40	4.6
<hr/> 43°03.3', 86°26.8'		
628	0	10.0
	2	10.0
	3	9.1
	4	8.9
	5	8.8
	7	8.2
	9	8.0
	11	7.5
	12	7.2

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°03.3', 86°29.4'		
629	0	11.0
	2	10.9
	6	9.5
	10	8.0
	11	7.7
	15	6.9
	18	6.4
	22	6.1
	25	5.6
	29	5.1
	34	4.8
<hr/> 43°03.2', 86°31.9'		
630	0	11.0
	3	10.9
	5	9.8
	6	9.5
	8	8.3
	10	8.1
	12	7.8
	15	7.7
	17	7.3
	21	7.1
	25	6.7
	29	6.2
	31	5.8
	33	5.2
<hr/> 43°03.2', 86°34.5'		
631	0	10.4
	1	10.3
	3	9.4
	5	8.8
	7	8.3
	10	8.2
	15	8.0
	17	7.8
	25	7.7
	35	7.2
	40	7.2
<hr/> 43°03.1', 86°37.0'		
632	0	9.1
	2	9.1
	4	7.9
	5	7.7
	8	7.4
	12	7.2
	15	6.9
	17	6.4
	42	5.4
<hr/> 43°03.1', 86°39.5'		
633	0	9.7
	2	9.2

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°03.1', 86°42.0'		
634	0	9.4
	2	8.9
	5	8.5
	7	7.8
	14	6.9
	16	6.6
	30	6.1
	33	5.8
	37	5.7
	46	5.3
	56	4.8
	60	4.6
	65	4.5
	74	4.3
	104	4.3
<hr/> 43°03.1', 86°44.6'		
635	0	9.4
	2	9.1
	3	8.8
	5	7.9
	6	7.7
	9	7.5
	14	6.7
	21	6.4
	27	5.7
	29	5.6
	32	5.2
	41	4.7
	44	4.6
	60	4.4
	95	4.3
<hr/> 43°03.1', 86°47.3'		
636	0	9.3
	1	9.2
	3	7.4
	14	6.3
	17	6.2
	25	6.0
	34	5.4
	38	4.7
	56	4.2
	60	4.2
	71	4.2
	85	4.1

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°03.1', 86°49.8'		
637	0	9.8
	2	9.7
	4	7.6
	5	7.4
	7	7.2
	10	6.7
	19	6.3
	21	6.0
	31	5.5
	41	5.0
	60	4.5
	71	4.3
	84	4.3
<hr/> 43°03.0', 86°52.3'		
638	0	9.5
	4	9.0
	5	7.9
	7	7.5
	10	7.2
	12	6.5
	17	6.2
	23	6.1
	44	4.6
	52	4.4
	60	4.3
	71	4.2
	80	4.1
	90	4.1
<hr/> 43°03.0', 86°54.9'		
639	0	9.5
	4	8.8
	5	8.4
	6	7.8
	10	6.8
	25	6.3
	34	5.7
	38	5.5
	45	5.1
	53	4.4
	60	4.3
	89	4.2
<hr/> One cast missed. (winch failure)		
<hr/> 43°03.0', 86°59.9'		
640	0	11.0
	1	11.0
	3	10.6
	4	10.4
	7	8.9
	10	8.4
	12	7.8
	17	7.4
	28	5.4
	35	4.8
	38	4.7
	47	4.5

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 640		
	60	4.2
	71	4.1
	86	4.1
<hr/> Two casts missed. (winch failure)		
<hr/> 43°03.0', 87°07.6'		
641	0	11.3
	1	11.3
	4	9.6
	7	9.1
	15	8.5
	16	7.3
	19	6.7
	23	4.8
	29	4.4
	60	4.2
	73	4.1
<hr/> 43°02.9', 87°10.4'		
642	0	11.4
	1	11.3
	3	9.2
	11	7.4
	19	6.4
	29	5.7
	32	5.4
	38	5.0
	60	4.4
	77	4.3
<hr/> 43°02.9', 87°13.3'		
643	0	10.6
	1	10.4
	2	9.7
	4	9.5
	12	7.1
	15	5.7
	21	5.0
	29	4.6
	53	4.4
	56	4.2
	60	4.1
	83	4.0
<hr/> 43°02.8', 87°15.8'		
644	0	11.4
	1	11.4
	4	9.2
	9	8.3
	17	5.8
	23	4.8
	34	4.5
	42	4.1
	60	4.0
	65	4.0
	80	3.8
<hr/> 43°02.8', 87°18.4'		
645	0	12.2
	1	12.2
	2	11.7

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 645		
	5	11.5
	7	9.8
	16	8.1
	21	4.8
	28	4.1
	60	3.8
	77	3.6
<hr/> 43°02.8', 87°21.0'		
646	0	12.4
	2	11.9
	4	10.9
	10	10.3
	21	5.4
	28	4.4
	60	4.0
	83	4.0
<hr/> 43°02.8', 87°23.6'		
647	0	12.2
	2	11.8
	3	9.9
	6	8.9
	12	8.4
	14	6.4
	18	4.7
	22	4.3
	33	4.1
	60	4.0
<hr/> 43°02.8', 87°26.3'		
648	0	11.9
	11	7.8
	17	6.1
	22	5.6
	23	5.1
	27	4.9
	48	4.4
	60	4.3
	69	4.1
	89	4.1
<hr/> TRANSECT TURNS NORTHWARD		
<hr/> 43°05.7', 87°26.7'		
649	0	14.2
	3	12.0
	6	10.9
	10	10.3
	12	8.6
	18	5.6
	22	4.9
	48	4.4
	60	4.4
	92	4.2
<hr/> TRANSECT TURNS NORTHWESTWARD		
<hr/> 43°07.6', 87°29.3'		
650	0	14.4
	1	13.0
	3	12.8

Slide No.	Depth, M Corr.	Temp. °C Corr.
650	4	11.0
	9	10.1
	15	7.7
	18	7.1
	21	6.3
	27	5.5
	36	5.1
	60	4.8
	86	4.6
<hr/> 43°08.2', 87°30.0'		
651	0	14.4
	4	13.7
	7	12.5
	9	10.9
	11	10.0
	13	9.5
	15	9.1
	18	7.5
	21	7.0
	36	5.9
	60	5.4
	88	5.1
<hr/> 43°09.4', 87°31.8'		
652	0	15.0
	1	13.2
	9	9.6
	11	8.8
	13	7.8
	15	6.1
	16	5.7
	23	4.9
	30	4.6
	60	4.2
	63	4.2
<hr/> 43°10.6', 87°33.6'		
653	0	14.7
	3	12.4
	6	11.3
	8	10.5
	15	6.4
	19	4.7
	21	4.5
	27	4.2
	36	4.1
	60	4.1
	67	4.1
<hr/> 43°11.8', 87°35.2'		
654	0	15.0
	2	12.2
	3	12.2
	4	10.8
	6	10.2
	8	9.8
	14	9.8
	18	9.6
	21	7.4
	23	7.2

Slide No.	Depth, M Corr.	Temp. °C Corr.
654	28	4.8
	35	4.4
	60	4.1
	74	4.1
<hr/> 43°13.0', 87°37.1'		
655	0	15.2
	3	14.1
	5	12.5
	15	10.7
	23	5.6
	25	5.2
	33	4.5
	45	4.2
	60	4.2
<hr/> 43°14.3', 87°38.9'		
656	0	14.9
	1	14.9
	4	12.4
	5	12.0
	6	11.0
	8	10.4
	14	9.6
	17	8.0
	20	7.0
	22	6.0
	26	4.9
	30	4.6
	36	4.2
	60	4.0
	114	3.7
<hr/> 43°15.9', 87°40.7'		
657	0	15.0
	1	15.0
	3	13.0
	6	10.3
	7	10.0
	9	9.9
	12	8.3
	13	8.0
	18	5.8
	23	5.0
	27	4.9
	60	4.4
	102	4.0
<hr/> 43°16.7', 87°42.3'		
658	0	15.2
	1	12.6
	3	12.0
	4	10.5
	5	10.0
	23	5.1
	60	4.1
	104	3.9
<hr/> 43°17.8', 87°44.0'		
659	0	14.6
	1	14.5
	3	12.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
659	5	9.7
	9	8.3
	14	7.0
	15	6.5
	22	5.2
	33	4.6
	42	4.2
	60	3.9
	90	3.7
<hr/> 43°19.1', 87°45.7'		
660	0	15.4
	2	12.0
	4	11.6
	6	9.7
	16	8.1
	22	6.0
	30	4.9
	39	4.3
	45	4.2
	60	4.1
	72	4.0
<hr/> 43°20.3', 87°47.5'		
661	0	15.4
	1	12.5
	2	11.9
	3	11.7
	7	9.9
	11	9.4
	15	7.3
	23	6.5
	26	5.7
	39	5.1
	52	5.0
<hr/> 43°21.5', 87°49.1'		
662	0	15.5
	2	12.0
	5	9.9
	8	9.2
	11	7.8
	22	6.4
	30	6.2
<hr/> 43°22.7', 87°50.8'		
663	0	15.5
	2	12.4
	3	11.8
	4	11.4
	6	9.8
	8	8.7
	10	8.4
	15	8.2
<hr/> Trace lost.		

South of Muskegon to North of Milwaukee
24 July 1963

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°06.5', 86°18.0'		
669	0	20.2
	5	19.4
	7	18.6
	8	17.0
	9	16.7
<hr/> 43°06.6', 86°20.7'		
670	0	20.4
	3	17.8
	5	16.7
	8	13.1
	13	7.5
	20	6.8
	24	6.7
	28	6.6
<hr/> 43°06.7', 86°22.9'		
671	0	20.8
	2	19.5
	3	16.6
	4	15.2
	7	11.6
	10	9.9
	16	8.8
	25	6.3
	33	6.0
	40	5.9
<hr/> 43°06.8', 86°25.9'		
672	0	20.4
	1	18.2
	2	14.9
	3	13.8
	5	11.6
	9	9.6
	13	8.0
	16	7.8
	20	6.9
	31	6.2
	40	5.9
	48	5.7
	60	5.6
<hr/> 43°06.9', 86°28.0'		
673	0	20.6
	2	19.3
	3	13.2
	5	11.0
	11	7.6
	17	7.0
	23	6.5
	29	6.3
	38	6.2
	65	5.9
	71	5.7
	77	5.7
	90	5.6

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°07.0', 86°30.8'		
674	0	19.9
	1	18.2
	4	13.5
	13	8.2
	17	7.2
	23	6.7
	29	6.4
	60	5.9
	102	5.6
<hr/> 43°07.1', 86°32.9'		
675	0	18.3
	2	18.2
	5	14.8
	7	13.2
	11	8.8
	12	8.2
	20	7.1
	23	6.7
	29	6.5
	35	6.3
	54	6.0
	84	5.6
	106	5.6
<hr/> 43°07.2', 86°35.3'		
676	0	18.7
	4	18.0
	6	13.2
	8	11.6
	14	9.6
	15	8.6
	18	8.0
	23	7.1
	25	6.8
	30	6.6
	55	6.0
	79	5.8
	106	5.6
<hr/> 43°07.3', 86°37.7'		
677	0	19.2
	4	16.6
	5	15.9
	7	13.2
	12	10.7
	15	8.6
	18	7.7
	21	7.1
	24	6.8
	30	6.5
	53	5.9
	61	5.7
	91	5.6
	101	5.6

Slide No.	Depth, M Corr.	Temp. °C Corr.
<hr/> 43°07.4', 86°40.4'		
678	0	18.9
	3	17.4
	8	9.9
	9	9.2
	11	8.5
	17	7.1
	37	6.3
	63	5.8
	106	5.6
<hr/> 43°07.5', 86°42.6'		
679	0	19.0
	5	14.4
	10	8.9
	13	8.2
	14	7.6
	17	7.1
	29	6.5
	42	6.3
	66	6.0
	78	5.8
	106	5.6
<hr/> 43°07.6', 86°45.3'		
680	0	18.9
	1	18.7
	2	18.3
	4	15.0
	6	10.6
	8	8.9
	9	8.3
	12	7.8
	14	7.2
	17	6.7
	30	6.3
	61	5.8
	79	5.7
	85	5.7
	99	5.6
<hr/> 43°07.7', 86°47.8'		
681	0	19.5
	1	18.6
	3	17.2
	4	15.0
	7	10.0
	9	8.3
	11	8.0
	12	7.5
	15	7.1
	18	6.8
	24	6.6
	30	6.3
	61	5.7
	96	5.6

No.	Corr.	Corr.
<hr/> 43°07.8', 86°50.4'		
682	0	19.2
	4	14.7
	6	8.3
	8	7.8
	17	7.2
	24	6.7
	30	6.3
	41	5.9
	61	5.7
	93	5.6
<hr/> 43°07.9', 86°53.0'		
683	0	19.8
	1	18.8
	4	14.3
	7	12.7
	10	9.9
	14	8.2
	18	7.3
	26	6.6
	41	5.9
	47	5.7
	87	5.6
<hr/> 43°08.0', 86°55.8'		
684	0	20.1
	4	15.6
	8	12.6
	10	10.0
	12	8.3
	15	7.4
	23	6.8
	37	6.0
	46	5.8
	52	5.7
	89	5.6
<hr/> 43°08.1', 86°58.0'		
685	0	20.2
	3	15.5
	7	14.1
	12	8.9
	15	8.2
	21	7.1
	28	6.3
	43	5.8
	52	5.7
	90	5.6
<hr/> 43°08.2', 87°00.6'		
686	0	20.5
	3	15.5
	8	13.2
	14	8.2
	17	7.1
	22	6.6
	29	6.2
	60	5.7
	88	5.6

No.	Corr.	Corr.
<hr/> 43°08.3', 87°02.9'		
687	0	20.3
	2	18.8
	5	15.7
	11	11.6
	13	9.9
	19	7.7
	23	6.7
	30	6.2
	39	5.9
	48	5.7
	60	5.7
	86	5.6
<hr/> 43°08.4', 87°05.8'		
688	0	20.5
	2	18.8
	4	11.8
	15	8.1
	19	7.1
	28	6.1
	41	5.7
	81	5.6
<hr/> 43°08.5', 87°08.9'		
689	0	20.9
	1	20.0
	12	9.4
	13	8.3
	21	6.5
	24	6.1
	30	5.9
	42	5.7
	81	5.6
<hr/> 43°08.6', 87°10.6'		
690	0	20.9
	2	19.9
	7	17.2
	11	12.8
	14	10.0
	18	7.4
	21	6.7
	27	5.9
	49	5.7
	76	5.6
<hr/> 43°08.7', 87°13.3'		
691	0	20.9
	1	20.5
	2	19.3
	6	18.2
	11	12.7
	16	8.2
	17	7.8
	28	6.2
	36	5.9
	48	5.6
	70	5.6
<hr/> 43°08.8', 87°15.9'		
692	0	20.8
	1	19.6
	5	16.7

No.	Corr.	Corr.
<hr/> 692		
	10	11.6
	14	8.6
	23	6.0
	42	5.6
	54	5.6
	77	5.6
<hr/> 43°08.9', 87°18.1'		
693	0	20.9
	3	18.2
	5	14.6
	8	10.5
	12	7.7
	17	6.7
	25	5.7
	29	5.6
	41	5.6
	75	5.6
<hr/> 43°09.0', 87°20.9'		
694	0	21.0
	2	18.9
	4	16.5
	6	11.7
	8	10.0
	11	8.3
	12	7.2
	17	6.3
	23	5.8
	35	5.6
	41	5.6
	70	5.6
<hr/> 43°09.1', 87°23.3'		
695	0	21.0
	4	15.6
	10	9.2
	15	7.4
	18	6.6
	30	5.8
	74	5.6
<hr/> 43°09.2', 87°25.4'		
696	0	20.8
	3	18.3
	12	8.9
	16	7.2
	21	6.4
	30	5.9
	49	5.7
	61	5.6
<hr/> 43°09.3', 87°29.0'		
697	0	21.0
	1	20.0
	4	16.1
	8	13.9
	12	8.9
	18	6.4
	24	6.1
	37	5.7
	72	5.6
<hr/> 43°09.4', 87°31.8'		
698	0	21.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
698	5	15.6
	12	7.8
	16	7.5
	20	6.8
	26	6.0
	32	5.8
	35	5.7
<hr/> 43°09.4', 87°34.5'		
699	0	20.5
	4	16.9
	11	10.0
	16	8.3
	20	7.2
	25	6.4
	31	5.9
	37	5.7
	50	5.7
	77	5.6
<hr/> 43°09.5', 87°37.1'		
700	0	20.3
	5	15.6
	14	10.4
	17	9.4
	23	7.2
	26	6.7
	29	6.3
	37	6.0
	43	5.8
	61	5.7
	87	5.6
<hr/> 43°09.6', 87°40.0'		
701	0	20.7
	2	19.4
	6	14.2
	16	8.3
	19	6.8
	25	6.2
	32	5.8
	35	5.7
	84	5.6
<hr/> 43°09.7', 87°42.9'		
702	0	20.7
	2	19.6
	8	12.6
	14	7.8
	23	6.7
	29	6.0
	54	5.8
	83	5.6
<hr/> 43°09.8', 87°45.4'		
703	0	20.7
	2	16.3
	4	14.1
	9	10.2
	13	7.5
	17	6.6
	28	6.0

Slide No.	Depth, M Corr.	Temp. °C Corr.
43°09.8', 87°47.6'		
704	0	20.9
	3	15.0
	5	11.4
	9	8.9
	13	7.2
	16	6.5
	23	6.0
	33	5.7
	59	5.6
<hr/> 43°09.8', 87°50.4'		
705	0	21.5
	1	19.4
	5	13.9
	7	8.9
	9	7.1
	23	6.7
	29	6.7

Slide No.	Depth, M Corr.	Temp. °C Corr.
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STUDIES ON WATER MOVEMENTS AND SEDIMENTS IN
SOUTHERN LAKE MICHIGAN

Part II. The Surficial Bottom
Sediments in 1962-1963

John C. Ayers

Jack L. Hough

ORA Project 05466

Part II of the Final Report of
H.E.W. Contract PH-86-63-60

GREAT LAKES RESEARCH DIVISION
Special Report No. 19

INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

January 31, 1964

PREFACE TO THE ENTIRE REPORT

Several factors have dictated that this final report should be in separate parts.

The contract covered studies of different sorts. By the nature of the studies, the times required for work-up and analysis of data have varied widely, some parts being completed long before others could be finished. The different studies have required greatly varying amounts of ship-time and some, which required unexpectedly large amounts of ship-time, are being augmented by data obtained during cruises for other projects when vessels are in suitable regions. Finally, it is believed that assimilation by the reader is aided by brevity and unit reporting.

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INTRODUCTION

This study of present-day surficial bottom sediments of the southern basin of Lake Michigan was carried out for two reasons: to expand and complete the coverage obtained by Hough (1935), and to ascertain whether there have taken place any recognizable changes in the composition of the bottom sediments in the thirty years that have lapsed since his studies.

Hough, operating from a small sailboat with little gear and insufficient help, was able to cover a significant portion of the southern basin. His coverage was sufficient that if sediment changes have taken place as a result of eutrophication, they should be detectable.

If the eutrophication process has not yet progressed to the point where there has been recognizable change of sediment type, Hough's map of bottom sediments should be filled in and made as complete as possible in order that there may be a map against which to determine the onset of eutrophication-caused sediment-type changes if they occur in the future.

METHODS

The 524 samples upon which this report is based are indicated in Figure 1.

The samples were for the most part in lines roughly perpendicular to shore, the lines being from five to 15 miles apart. In each line the sampling intervals usually were: at one-mile intervals from the 1st through the 10th mile from the beach, at 2-mile intervals from the 10th through the 20th mile, and at 5-mile intervals thereafter. In the center of the basin 23 samples were taken in four lines down the slope toward the deepest portion. A single sample was taken off, and between, the lakeward ends of lines IV and V. Figure 1 shows that coverage of the basin is not complete, and that an additional line is needed between lines XXVIII and XXIX.

The sample numbers, distances from shore, depths of water, and field descriptions of the sediments are given in the Appendix. Sample numbers are consecutive by time of taking. Some lines were taken on courses toward shore, others on courses away from shore.

With the exception of about eighteen samples, all samples were taken with the dwarf orange-peel sampler. Fifteen of the samples were cores and two or three were obtained with the Smith-McIntyre sampler (a spring-loaded modification of the Petersen dredge).

Navigation was by radar range and bearing out to about the 20th mile, beyond which navigation was by dead-reckoning.

The bathymetry shown in Figure 1 was provided by Prof. Hough

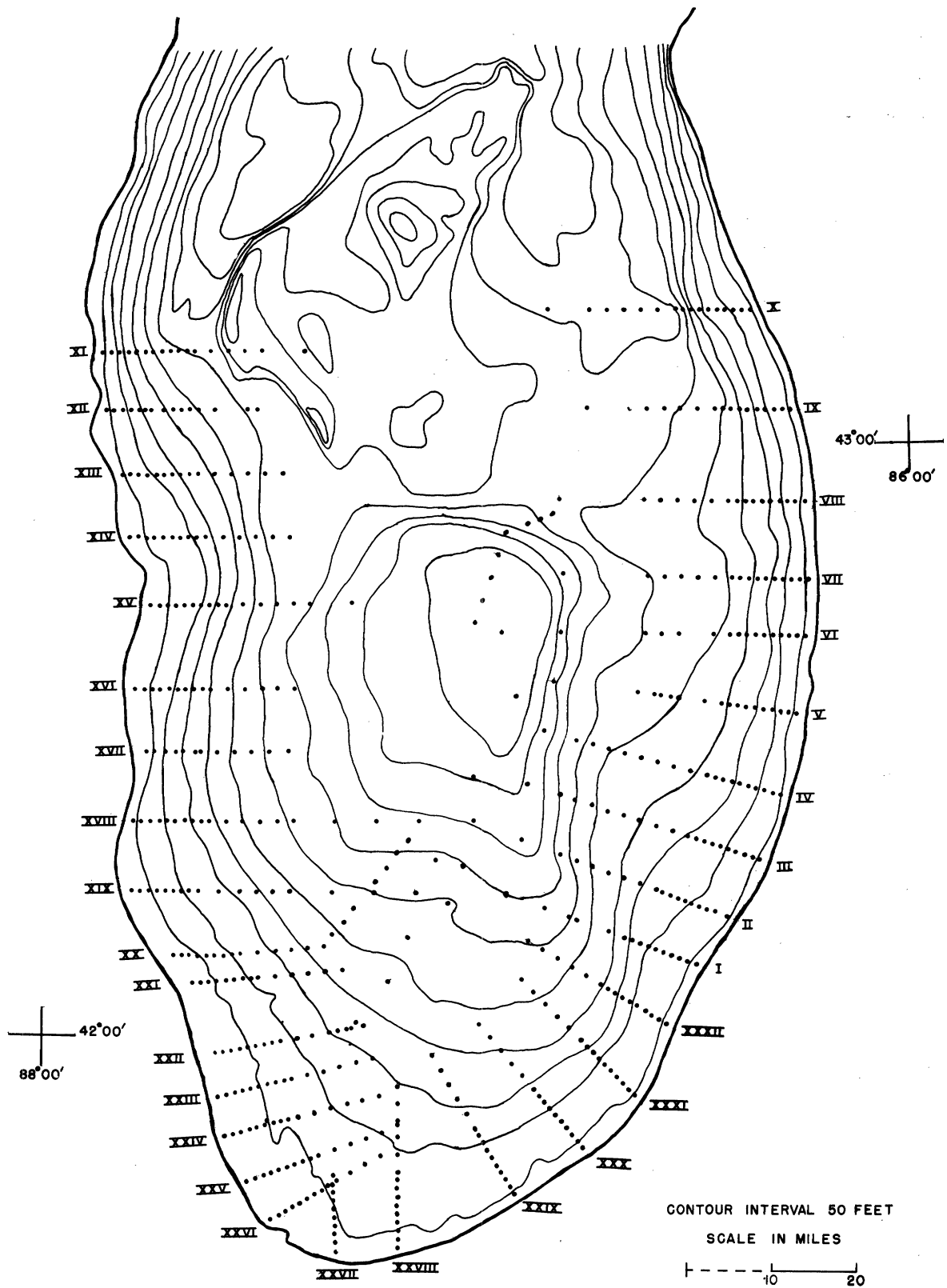


Fig. 1. Present bathymetry and sampling locations, survey of 1962-1963.

and was derived from the detailed field sheets (boat sheets) of the U. S. Lake Survey. This bathymetry represents the best-possible synthesis of all the sounding data of the Lake Survey up to the present. The depth-contour interval is 50 feet.

Figure 2 presents Hough's 1935 sediment map, reproduced without latitude-longitude lines or state lines. It is also without three 90-fathom depth contours in the deepest portion, these depths having proven to be false.

The bathymetry of Figure 2 was constructed by Prof. Hough in the early 1930's and represents the then best-possible synthesis of the Lake Survey data of that time. The depth-contour interval of this figure is 10 fathoms.

Figure 3 presents the results of our bottom sediment survey. It is necessary to explain here certain aspects of the preparation of this map.

The edges of the several sediment types in Figure 3 have been placed halfway between the pairs of differing samples that require a boundary somewhere between them. Probably a certain amount of error in the positioning of boundaries has resulted from this practice.

In the north-central portion of the basin, where boundaries appear to cross the basin but where additional samples are needed, question marks along the boundaries indicate our uncertainty as to their locations.

This map was prepared from the field descriptions of sediment type(s). By "field description" is meant a phenotypic description based upon combined visual inspection, testing for odor, and feeling of the sediment with the fingers. Field description

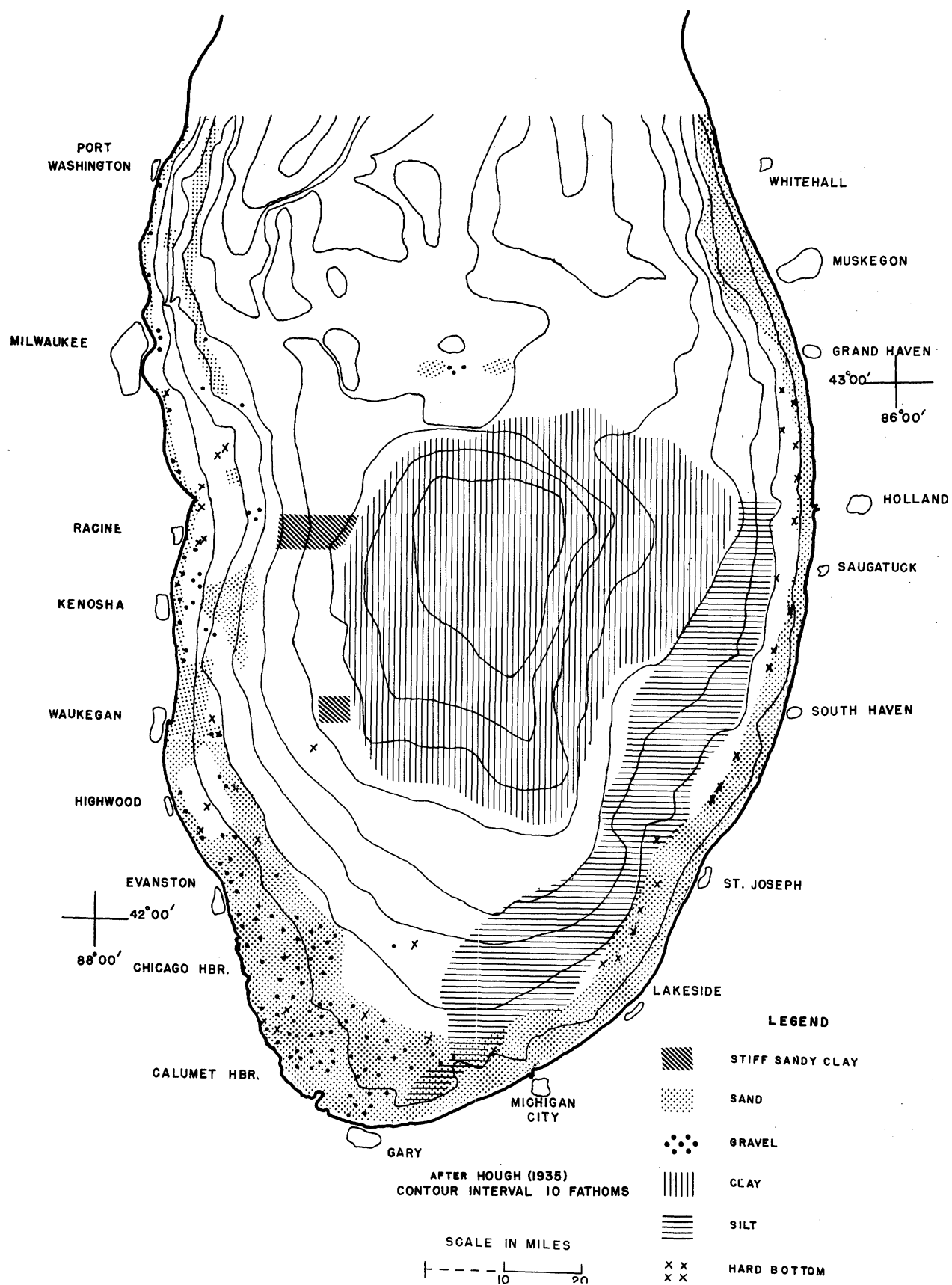


Fig. 2. Hough's 1935 sediment map and bathymetry.

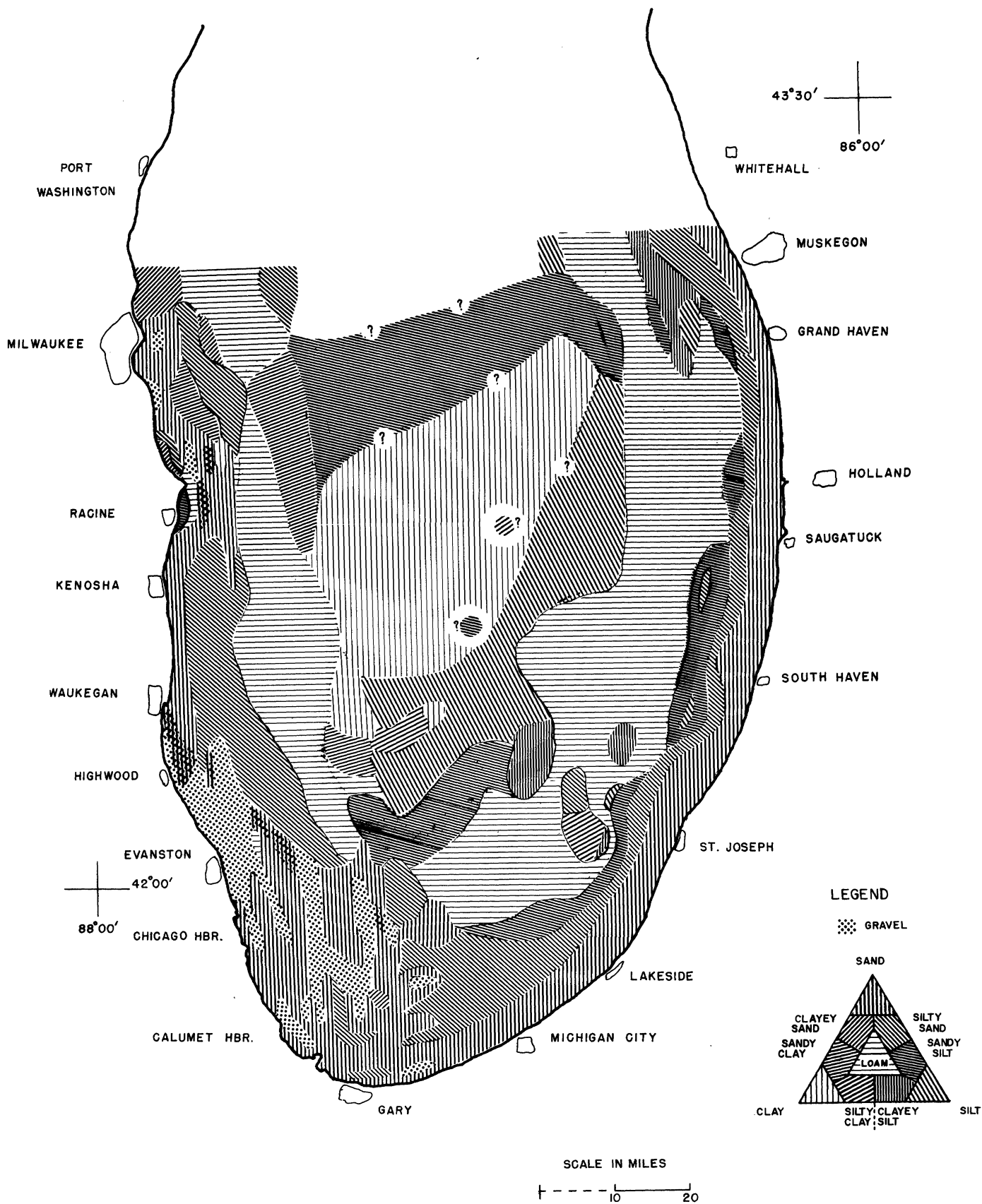


Fig. 3. The surficial sediments of 1962-1963.

is a combination of the observations carried out on board ship, when the sample was fresh, and re-examination of the material in the laboratory under a binocular microscope with a metric scale in the field of view. The term is used as an opposite to any of the several means of designating sediment type by the measured proportions of sand, silt, and clay determined in particle-size analyses.

Each sample has been placed subjectively in a sediment-type category on the basis of the field description of the uppermost sediment layer, even if it was only a thin surface layer.

The sediment-type categories used follow the triangular-graph categorization of Shepard (1954) except that a subjective basis rather than a percentage-composition basis is used. "Loam" in the center of the triangle represents the several 3-way combinations of sand, silt and clay (sandy silty clay, clayey sandy silt, silty clayey sand, etc.).

The use of only the uppermost sediment layer was dictated by the fact that sediment-type changes resulting from eutrophication will first be evident in the thin surficial layers.

The use of the field description of sediment type was necessary for three reasons: 1) eutrophication-caused changes will probably be first visible as significant color changes in the surface layer as it modifies toward the organic sediments (if not between Hough's survey and this, then between this and some future survey), 2) the presence of unnatural odors is detected most surely in the field observation of the fresh sediment, and 3) sufficient funds for the scraping-off and analysis of samples of the uppermost sediment layer were not available.

RESULTS AND DISCUSSION

The basic purpose of this report is to present the tabulated data of the Appendix, but in order that these data may be visualized Figure 3 has been prepared.

Comparisons between Figures 2 and 3 are the present best available means of determining whether the intervening period of 30 years has produced differences in the composition of the surficial sediments.

In one sense these figures are only partially comparable: Figure 2 is based upon the results of particle-size analyses augmented by field descriptions obtained from U. S. Lake Survey charts; Figure 3 is based only upon field descriptions. Incomparability becomes greatest in cases where a thin layer of a sediment of one type overlies a thick layer of a sediment of a different type. Particle-size analysis of a split "representative sample" gives most statistical weight to the thicker second layer and is not apt to detect the environmental change represented by the thin surficial layer. Plots of field descriptions of the uppermost layer, however thin it may be, take no account of the underlying layer(s) and are not based upon the concept of the "representative sample" or aliquot thereof.

Fortunately, the numbers of cases where greatly different sediment types occur in layered configurations are not numerous. For this reason there is a degree of justification for cross-comparisons between Figures 2 and 3.

Comparisons of Figures 2 and 3

The primary result of comparison of these figures is that

over most of the lower lake, there is no conclusive demonstration of change in the surficial sediments since the early 1930's.

In the central portion of the basin apparent differences in sediment types involve, in large part, those distinctions between proportions of sand and silt or silt and clay that are least accurately made by the field descriptions. The apparent differences are believed not to be real, but rather effects of masking (in Fig. 2) due to the weight given to a second thicker layer by partical-size analysis of representative samples.

Along the shores there are but minor differences between the two figures. The differences for the most part, again, involve the judgment of proportions of sand and silt or silt and clay.

In the area off Chicago and its environs there are some differences in position of gravel and sand in the two figures. These sediments are quite accurately assessed by the field description; they also are sediments more apt to be non-layered through the depths reached by a grab sampler. The positional differences are taken to indicate that sand bars move or migrate in the region off Chicago.

The more complete spatial coverage upon which Figure 3 is based allows the elimination of open spaces (terrae incognitae) that were necessary in Figure 2. It is to be noted, however, that our coverage is not complete, and that some sediment-type boundaries will move if more-closely spaced samples are obtained.

Samples of Special Note

In only eight of the samples were there evidences that man's activities have resulted in modification of the native lake-bottom

sediments. These samples, their locations, and their field descriptions are given in Table 1.

Table 1. Samples of Special Note

Sample No.	Location	Description
I-11	ca 12 miles, 290° true, off Benton Harbor	<u>Black</u> sandy clayey silt over brown sandy silt over gray silt.
XXV-1	1 mile, 70° true, off Calumet Harbor	Gravel over gray stiff sandy clay. <u>Foul odor</u> .
XXVI-6	8 miles, 60° true, off Indiana Harbor	Mottled gray and brown silty fine sand. <u>Odor of oil</u> .
XXVI-7	7 miles, 60° true, off Indiana Harbor	Mottled gray and brown silty fine sand. <u>Odor of oil</u> .
XXVI-8	6 miles, 60° true, off Indiana Harbor	Fine sand with some organic matter, cinders, wood. <u>Odor of oil</u> .
XXVII-6	6 miles, 0° true, off Gary, Indiana	Coarse sand. <u>Odor of oil</u> .
XXVII-7	7 miles, 0° true, off Gary, Indiana	Dark gray silty very fine sand with some vegetable matter. <u>Strong odor of oil</u> .
XXVIII-5	5 miles, 0° true, off Burns Ditch	Coarse sand-fine gravel over gray silty very fine sand. <u>Odor of oil</u> .

In Table 1 there have not been included a few samples in which cinders were present. Nor does the table include samples XXIII-5 or XXIII-6 (5 and 6 miles off Chicago Harbor) which contained, respectively, pieces of ceramic tile and rusty nails. These are mentioned here as evidences of dumping activity past or present, but are omitted from the table as being of little significance to the eutrophication process.

The black surface sediment of sample I-11 is of interest because it was the only sample of the survey whose color was sufficient to be called black. There are numerous instances of gray sediments which cannot be shown to be related to eutrophication (though it is suspected that some are).

Sample I-11 appears to be too distant and too far west to be a reflection of organic contributions from the St. Joseph River. At present nothing is known of the origin of its black color.

The Area of Possibly Modifying Sediments

The remaining seven samples of Table 1 may represent: 1) incipient modification of lake-bottom sediments as a result of man's activities, or 2) temporary effects of dumping of petroleum products, or 3) temporary results of shipwreck of tankers or oil barges in the region.

From the data presently at hand it cannot be ascertained which of the three possibilities above is(are) responsible for the oil odor in the sediments.

Despite our inability to assign a cause or causes it is significant that the sediments of an area ranging from one to three miles wide and more than 15 miles long, situated in the heavily-populated heavily-industrialized end of the lake, have been found to exhibit deteriorative effects attributable to man. Even if the present effects prove to be temporary, the area in which they occur should be well-noted as an area where definitive eutrophic deterioration should be watched for.

SUMMARY AND CONCLUSIONS

1. Five hundred and twenty-four samples of the surficial sediments taken in 1962-63 are the basis of this report. The coverage represented is good, though not complete.
2. Comparison of this survey to that of Hough (1935) does not demonstrate changes in sediment type as such over the 30-year intervening period.
3. Seven samples in the southern extremity of the lake (off Calumet Harbor, Indiana Harbor, Gary, and Burns Ditch) give olfactory evidence that organic materials are being incorporated into the sediments, though the process appears to have not yet gone to the point of causing changed sediment-type or changed sediment color.
4. Six of these seven samples indicate the incorporation of oil into the sediment.
5. It is suggested that the region where oil odor is now present is one that should be watched for evidences of future definitive eutrophic deterioration.

REFERENCES

- Hough, J. L. 1935. The bottom deposits of southern Lake Michigan. Jour. Sed. Petrol., 5(2) 57-80.
- Shepard, F. P. 1954. Nomenclature based on sand-silt-clay ratios. Jour. Sed. Petrol., 24(3) 151-158.

APPENDIX

Sample numbers, sample positions, and field descriptions of sediment types. Bottom samples taken between 7 August 1962 and 18 November 1963. All compass directions indicated are in degrees true.

Line I; bearing 290° from Benton Harbor pierhead

Sample No.	Miles from Pierhead	Depth (feet)	Description
1	1	53	Medium sand
2	2	67	Fine sand
3	3	76	Fine sand
4	4	84	Very fine sand
5	5	93	Silty very fine sand
6	6	106	Silty very fine sand
7	6.9	115	Silty very fine sand
8	8	128	Very-fine-sandy silt
9	9	147	Very-fine-sandy silt
10	10	175	Dark gray silt
11	12 ?	250	Black sandy clayey silt over brown sandy silt over gray silt
12	16	282	Brown silty sand
13	17	304	Brown sandy clayey silt
14	20	334	Grayish-brown clayey silt
15	25	365	$\frac{1}{4}$ " gray sandy silt over red-brown slightly-sandy soft clay

" = inch

Line II; bearing 110° from E. shore, 6.7 miles N.E. of
Benton Harbor pierhead

Sample No.	Miles from Shore	Depth (feet)	Description
16	1	52	Fine sand
15	2.5	66	Very fine sand
14	3.4	73	Medium-coarse sand
13	4.4	83	Medium-fine sand
12	5.4	91	Fine-to-very-fine sand
11	6.3	99	Grayish-buff silty very fine sand
10	7.2	108	Grayish-buff silty very fine sand
9	8.2	119	Gray sandy clayey silt
8	9.2	126	Gray sandy clayey silt
7	10.1	134	Gray sandy clayey silt
6	12	156	Gray clayey silt
5	14	199	Gray clayey silt
4	16	233	Gray slightly-sandy clayey silt
3	18	255	Grayish-buff sandy clayey silt
2	20	285	Grayish-buff sandy clayey silt
1	22	358	Grayish-buff sandy clayey silt
17	27	427	1/16" gray silt over gray slightly-sandy silty clay
18	33	425	1/2" gray silt over 1" of layered clay structure in 1/8" layers. First four layers of gray clay then alternating layers of gray and orange slightly-sandy clay; below last layer of orange clay a fine line of black. Clay below black line shades from gray to red-brown and is soft sandy clay.

Line III; bearing 287° from E. shore 7.2 miles S. of
South Haven light

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	49	Fine sand
2	2	62	Medium sand
3	3	88	Silty very fine sand
4	4	100	Silty fine-to-medium sand
5	5	110	Grayish-brown sandy coarse silt
6	6	119	Brownish-gray sandy silt
7	7	131	Gray silt
8	8	139	Gray sandy very fine silt
9	9	149	Gray sandy clayey silt
10	10	158	Gray slightly-sandy clayey silt
11	12	174	Dark-gray slightly-sandy clayey silt
12	14	187	Dark-gray slightly-sandy clayey silt
13	16	210	Dark-gray slightly-sandy clayey silt
14	18	232	Dark-gray slightly-sandy clayey silt
15	20	247	Dark-gray slightly-sandy clayey silt
16	22?	263	Dark-gray slightly-sandy clayey silt
17	24?	298	Dark-gray slightly-sandy clayey silt
18	26?	340	Dark-gray slightly-sandy clayey silt
19	30	490	Brownish-gray very-slightly-sandy clayey silt

5 trials:
small sample

Line IV; bearing 105° from South Haven pierhead

Sample No.	Miles from Pierhead	Depth (feet)	Description
6	1	50	No sample, 3 trials
7	2	65	Medium sand
8	3	90	Fine sand
9	4	105	Grayish-brown fine sand and very fine sand
10	5	118	Grayish-brown very fine sand
11	6	132	Brownish-gray silty very fine sand
12	7	151	Gray very-fine-sandy silt
13	8	168	Gray very-fine-sandy silt
14	9	178	Brownish-gray very-fine-sandy silt
15	10	188	Dark gray slightly-sandy clayey silt
16	12	210	Dark gray slightly-sandy clayey silt
17	14	222	Dark gray slightly-sandy clayey silt
18	16	238	Dark gray slightly-sandy clayey silt
5	18	240	Dark gray slightly-sandy clayey silt
4	20	255	Gray slightly-sandy clayey silt
3	22?	273	Gray slightly-sandy clayey silt
2	24?	318	Dark gray slightly-sandy clayey silt
1	26?	348	Dark gray slightly-sandy clayey silt
19	30		Gray slightly-sandy slightly-clayey silt

Line V; bearing 277° from point on E. shore 10 miles N.
of South Haven

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	50	Fine sand
2	2	75	Fine sand
3	3	100	Very fine sand to fine sand
4	4	120	Silty very fine sand
5	5	140	Silty very fine sand
6	6	160	Very-fine-sandy silt
7	7	178	Very-fine-sandy silt
8	8	192	Gray very-fine-sandy fine silt
9	9	202	Buff silty very fine sand
10	10	215	Grayish buff very-fine-sandy silt
11	12	238	Grayish buff very-fine-sandy clayey silt
12	15	245	Grayish buff very-fine-sandy clayey silt
13	16	248	Grayish buff very-fine-sandy clayey silt
14	17.2	260	Grayish buff very-fine-sandy clayey silt
15	18	268	Grayish buff very-fine-sandy clayey silt
16	20	277	Grayish buff very-fine-sandy clayey silt
17	30	455	1/16" gray silt over brownish-gray very-slightly-sandy clayey silt

Line VI; bearing 90° through Saugatuck pierhead light

Sample No.	Miles from Pierhead	Depth (feet)	Description
15	1	50	Medium-fine sand
14	2	78	Very fine sand
13	3	90	Very fine sand
12	4	120	Very fine sand (with a few coarser sand grains)
11	5	143	Silty very fine sand
10	6	170	Silty very fine sand
9	7	193	Grayish-buff clayey very-fine-sandy silt
8	8	217	Grayish-buff very-fine-sandy clayey silt
7	9	230	Buff-gray very-fine-sandy clayey silt
6	10	243	Buff-gray very-fine-sandy clayey silt
5	12	266	Gray-buff clayey sandy silt
4	14	272	Gray-buff clayey sandy silt
3	16	285	Buff-gray sandy clayey silt
2	18	290	Buff-gray sandy clayey silt
1	20	310	Buff-gray sandy clayey silt
17	30	475	1/16" gray silt over brownish-gray very-slightly-sandy clayey silt
16	37		Gelatinous gritless gray silty clay

Line VII; bearing 270° from Holland pierhead light

Sample No.	Miles from Pierhead	Depth (feet)	Description
1	1	52	Medium-fine sand
2	2	78	Medium sand
3	3	109	Grayish-buff very fine sand
4	4	136	Grayish-buff silty very fine sand
5	5	167	Buff-gray very-fine-sandy silt
6	6	184	Buff-gray very-fine-sandy silt
7	7	208	Gray slightly-very-fine-sandy silt
8	8	223	Gray slightly-sandy clayey silt
9	9	242	Gray slightly-sandy clayey silt
10	10	253	Gray slightly-sandy clayey silt
11	12	263	Gray slightly-sandy clayey silt
12	14	269	Gray slightly-sandy clayey silt
13	16	278	Dark gray slightly-sandy clayey silt with layers of gray-buff clayey silty sand
14	18	282	Gray-buff clayey silty sand
15	20	298	Gray-buff clayey silty sand
16	30	360	1/4" brown-gray silt over 1/2" brown-gray sandy silt over red-brown soft sandy clay

Line VIII; bearing 270° from pierhead, Port Sheldon

Sample No.	Miles from Pierhead	Depth (feet)	Description
1	1	48	Fine sand
2	2	80	Medium sand
3	3	117	Sightly-silty very fine sand
4	4	138	Grayish-buff silty very fine sand
5	5	163	Gray clayey very-fine-sandy silt
6	6	180	Gray clayey very-fine-sandy silt
7	7	197	Gray clayey very-fine-sandy silt
8	8	213	Gray clayey very-fine-sandy silt
9	9	225	Gray very-fine-sandy clayey silt
10	10	232	Gray very-fine-sandy clayey silt
11	12	243	Buff-gray clayey silty sand
12	14	260	Buff-gray clayey silty sand
13	16	270?	Buff-gray clayey silty sand
14	18	283?	Buff-gray clayey silty sand
15	20	292	Gray very-fine-sandy clayey silt
16	30	334	1/4" brown-gray silt over 3/4" brown-gray sandy silt over red-brown soft sandy clay with small shells

Line IX; bearing 90° to E. shore at Grand Haven

Sample No.	Miles from Shore	Depth (feet)	Description
15	1	54	Medium sand (clean)
14	2	77	Fine sand (clean)
13	3	104	Slightly-silty fine sand, some coarse sand
12	4	136	Grayish-buff silty very fine sand
11	5	164	Grayish-buff very-fine-sandy silt, some medium sand
10	6	204	Grayish-buff very-fine-sandy silt, some medium sand
9	7	240	Gray-buff clayey silt, very few sand grains
8	8	266	Dark gray clayey sandy silt over light gray very-sandy silt over rusty-tan very-sandy silty clay
7	9	272	1/4" grayish-brown silt over dark gray sandy silt with black zones, over light grayish-buff silty sand
6	10	277	1/4" grayish-brown silt over dark gray sandy silt with black zones, over light grayish-buff silty sand
5	12	287	Brownish-gray clayey silt over brownish-gray very-sandy silt
4	14	312	Sandy silt; in layers of lighter and darker grays
3	16	330	Gray clayey very-sandy silt over clayey very-sandy silt with reddish-brown color
2	18	328	Gray clayey very-sandy silt over red-brown (almost Valders red) very-sandy silty clay
1	20	335	Gray sandy silt over reddish-brown very-sandy silt over "clay" (dark brown 1/16" thick) over "clay" (rusty brown 1/8" thick) over reddish-brown slightly-sandy silty clay
16	25	345	1/2" brown-gray sandy silt over red-brown soft sandy clay

Line X; bearing 270° from Muskegon pierhead

Sample No.	Miles from Pierhead	Depth (feet)	Description
1	1	55	Medium-fine sand (clean)
2	2	80	Medium sand
3	3	98	Medium-coarse sand, very slightly silty
4	4	118	Sandy buff silty very-fine-to-fine sand
5	5	127	Buff silty very-fine-to-fine sand
6	6	150	1/2" brownish gray silty fine sand over buff very-silty very-fine-to-fine sand
7	7	180	1/2" brownish gray silty fine sand over buff very-silty very-fine-to-fine sand
8	8	282	1/2" brownish gray silty fine sand over buff very-silty very-fine-to-fine sand
9	9	342	1/2" buff silty fine sand over 1-1/2" light gray silty fine sand over dark gray slightly-sandy clayey silt
10	10	352	1/8" buff clayey silt over dark gray clayey silt
11	12	355	1/16" buff clayey silt over 2" light gray slightly-sandy clayey silt over dark gray clayey silt
12	14	362	Clayey very-slightly-sandy silt, in thin zones: gray, rusty, brownish-black, rusty, gray, dark gray--from top down
13	16	375	Clayey very-slightly-sandy silt, in thin zones: gray-brown, red-brown, brownish-black, rusty, gray,--from top down
14	18	390	1/4" buff clayey very-slightly-sandy silt over dark gray clayey very-slightly-sandy silt
15	20	387	Clayey very-slightly-sandy silt: gray (1/2") over rusty (1/4") over medium gray
16	25		Gray gritless silt over red-brown gritless silt

Line XI; bearing 90° from point on W. shore about 9.5 miles
N. of Milwaukee light

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	63	Slightly-clayey medium-to-coarse sand
2	2	128	Slightly-clayey medium-to-fine sand
3	3	168	Slightly-clayey medium-to-fine sand
4	4	194	Slightly-clayey fine-to-very-fine sand
5	5	232	Slightly-clayey fine-to-very-fine sand
6	6	248	Buff-gray clayey sandy silt
7	7	262	Buff-gray clayey sandy silt
8	8	274	Buff-gray clayey sandy silt
9	9	278	Buff-gray clayey sandy silt
10	10	286	2" buff-gray clayey sandy silt over rusty-brown clayey silty sand
11	12	294	1-1/2" red-brown clayey sandy silt over red-brown stiff clayey sandy silt over clayey silt
12	14	307	1/2" gray clayey sandy silt over 1-1/2" brown-buff silty fine sand over gray silty clay
13	16	268	3/4" gray silty fine sand over reddish-buff clayey silty fine sand
14	18	265	1/2" gray silty fine sand over reddish-buff clayey silty fine- medium-coarse sand
15	20	233	1/2" gray silty fine sand over clayey silty fine-medium-coarse sand with pebble 8 cm long (Lower layer till?)
16	25		Limestone cobble, 13 cm x 8 cm; chert layer 1 cm thick on one face; black (powdery when dry) discoloration on surface of three faces

Line XII; bearing 90° from N. Point Light (about 2.8 miles
N. of Milwaukee)

Sample No.	Miles from Shore	Depth (feet)	Description
1	1.1	55	Coarse sand over stiff red clay
2	2.0	75	Gravel, up to 3 cm, over stiff sandy red clay
3	3.1	105	Medium sand, with 1/2" layer cinders at 1-1/2" depth
4	4.0	120	Medium sand, both buff and buff-gray; small pebbles (sample slumped; which material was on top is not known)
5	5.0	145	1" grayish buff silty medium-fine sand over brownish-buff silty fine sand
6	5.6	163	1" grayish-buff silty medium-fine sand over brownish-buff silty fine sand
7	6.4	180	1" grayish-buff silty medium-fine sand over brownish-buff silty fine sand
8	"8"	214	Brownish-buff clayey fine sand
9	9	230	Brownish-buff clayey fine sand with one pebble 1 cm in diameter
10	10	242	1/2" rusty-brown clayey silty medium-fine sand over brownish-buff clayey fine sand
10A	"11"	254	1/2" rusty-brown clayey silty medium-fine sand over brownish-buff clayey fine sand
11	12	264	Brownish-buff sandy silty clay
12	14	284	Reddish-buff sandy clayey silt with shell fragments
13	16	297	Reddish-buff sandy clayey silt with shell fragments
14	18	308	Slightly-sandy silty clay, gray with rusty brown layer
15	(19)	308	Gray slightly-sandy silty clay
16	25		Sand (fine, medium, coarse), chert cobble 6 cm x 6 cm x 1cm; limestone cobble 11 x 9 x 6 cm; both cobbles with black (powdery when dry) surface discoloration on 3 faces

Line XIII; bearing 90° from W. shore, 4.8 miles S. of
Milwaukee

Sample No.	Miles from Shore	Depth (feet)	Description
15	1	52	Gravel: including cobbles up to 10 cm diameter. Rocks mainly carbonates
14	2	67	Medium-to-coarse sand; gravel
13	3	73	Reddish-buff stiff sandy clay
12	4	78	Reddish-buff stiff sandy clay
11	5	92	Reddish-buff stiff sandy clay
10	6	107	Reddish-buff stiff sandy clay
9	7	120	Hard bottom. No sample, 4 trials
8	8	142	Slightly-silty medium sand, with few pebbles
7	9	163	Slightly-silty fine sand, with few granules
6	10	182	Grayish-buff slightly-silty medium sand
5	12	198	Grayish-buff slightly-silty medium sand
4	14	256	Thin cover of medium sand over reddish-grayish-buff sandy clay
3	16	292	Thin cover of medium sand over reddish-grayish-buff sandy clay
2	18	308	Thin cover of medium sand over reddish-grayish-buff sandy clay
1	20	313	Thin cover of layered medium sand over reddish-grayish-buff sandy clay. A few shells in the clay
16	25		1/2" gray slightly sandy silt over gritless reddish-grayish-buff clay

Line XIV; bearing 90° from W. shore stack, 12.2 miles S. of Milwaukee

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	47	Gray-buff clayey poorly-sorted coarse sand
2	2	58	Silty fine sand
3	3	57	Coarse sand over stiff gray clay
4	4	62	Gravel (3 pebbles, 5 to 7 cm long)
5	5	77	Medium-coarse sand
6	6	78	Medium-coarse sand over stiff grayish-red clay
7	7	88	Gravel, mainly 1 to 2 cm and 1 pebble 9 cm, over stiff grayish-red clay
8	8	102	Gray watery clay ca. 1 mm thick, over stiff grayish-red clay with a few small pebbles
9	9	122	Medium sand
10	10	143	Silty medium sand, few small pebbles
11	12 (11) ²	173	Clayey silty fine sand over stiff grayish-red clay
12	14 (13) ²	247	Clayey silty fine sand over stiff grayish-red clay
13	16 (15) ²	293	Grayish-brown sandy clay with zones of clayey medium sand with black coatings
14	18 (17) ²	332	Grayish-brown sandy clay with zones of clayey medium sand with black coatings plus shells in zones and in clay
15	20 (19) ²	334	Grayish-brown sandy clay with zones of clayey medium sand with black coatings (with few shells)
15	25		1/2" gray slightly-sandy silt over brownish-gray gritless clay

2 = by fathometer time marks

Line XV; bearing 90° from W. shore, Racine

Sample No.	Miles from Shore	Depth (feet)	Description
15	1	40	Gray fine-sandy silt
14	2	50	Gray clayey silty poorly-sorted coarse sand
13	3	58	1/8" of clean coarse sand and fine gravel over stiff grayish-red clay
12	4	72	Gravel (pieces up to 3.5 cm)
11	5	75	Clean medium sand, with few pebbles up to 2.8 cm
10	6	87	Clean medium sand, with few pebbles up to 2.2 cm
9	7	100	Clean medium sand, with very few pebbles up to 1.2 cm
8	8	146	Gray-buff clayey silty fine sand with a few granules
7	9	167	Gray-buff clayey silty fine sand
6	10	192	Gray-buff clayey silty fine sand
5	12	235	Gray-buff clayey silty fine sand
4	14	265	Gray-brown very-clayey silty fine sand
3	16	292	Grayish-brown sandy clay with zones of clayey medium sand with black coatings
2	18	323	Grayish-brown sandy clay with zones of clayey medium sand with black coatings
1	20	352	Gray soft clay
16	25		Gray gritless clay

Line XVI; bearing 90° from shore at Kenosha, Wisconsin

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	38	Medium-fine sand (clean)
2	2	55	Medium-fine sand, few pebbles to 1 cm (clean)
3	3	55	Pebble (1) 2 cm diameter
4	4	60	Medium-coarse sand (clean)
5	5	100	Grayish-buff silty very fine sand, small shells
6	6.1	133	Grayish-buff silty medium-fine sand
7	7	150	Grayish-buff silty fine sand
8	8	165	Grayish-buff silty fine sand, few granules
9	9.1	185	Medium-fine sand, few small pebbles and cinders (fairly clean)
10	10	210	Slightly-silty medium-fine sand, few granules and small pebbles (2nd trial, no sample)
11	12	247	1-1/8" brownish-buff clayey silty medium-fine sand over tough brownish-buff clayey silty medium-fine sand
12	14.1	270	1-1/8" brownish-buff clayey silty medium-fine sand over tough brownish-buff clayey silty medium-fine sand
13	16.1	280	1/2" brownish-buff clayey silty medium fine sand over brownish-red slightly-sandy clay, with shells; few small zones of black coated grains
14	18	330	Soft, dark-gray sandy clayey silt over grayish-buff clayey silty medium-fine sand over firm, brownish-red sandy clay
15	20	347	Soft, dark-gray sandy clayey silt over grayish-buff clayey silty medium-fine sand over firm brownish-red sandy clay

Line XVII; bearing 90° from W. shore near Winthrop Harbor

Sample No.	Miles from Shore	Depth (feet)	Description
13	1.5	46	Medium-coarse sand (clean)
12	2.5	72	Grayish-buff silty very fine sand
11	3.8	108	Grayish-buff silty medium-fine sand with few pebbles
10	5.0	143	Grayish-buff silty medium-fine sand over rusty-brown silty medium-fine sand
9	6.0	154	Grayish-buff silty medium-fine sand, few small pebbles
8	7.5	172	Grayish-buff silty medium-fine sand, few small pebbles
7	8.2	190	1/2" gray clayey silty medium-fine sand over brownish-buff clayey silty medium-fine sand
6	10.0	228	1/2" gray clayey silty medium-fine sand over brownish-buff clayey silty medium-fine sand
5	12.0	260	3/4" gray clayey silty fine sand over brownish-buff clayey silty medium-fine sand
4	14.0	284	1/4" gray clayey fine-sandy silt over brownish-red clayey silty fine sand
3	16.2	308	1/4" gray clayey fine-sandy silt over brownish-red clayey silty fine sand
2	18.5	336	3/4" gray sandy silty clay over reddish-brown sandy silty clay
1	21.0	358	Gray sandy silty clay

Line XVIII; bearing 90° from W. shore at Waukegan

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	38	Very fine sand
2	2	58	Fine sand
3	3	74	Medium-fine sand
4	4	90	Grayish-buff slightly silty medium-fine sand, few small shells
5	5	108	Grayish-buff silty medium sand
6	6	125	Grayish-buff silty medium sand (1 cinder)
7	7	145	Grayish-buff silty medium-coarse sand, few granules
8	8	158	Grayish-buff silty medium sand, few granules
9	9	169	Grayish-buff silty medium sand
10	10	183	Grayish-buff silty medium-fine sand
11	12	225	Reddish-brown clayey silty sand
12	14	250	3/4" gray clayey silty sand over reddish-brown clayey silty sand
13	16	265	3/4" gray clayey silty sand over reddish-brown clayey silty sand
14	18	280	3/4" gray clayey silty sand over reddish-brown clayey silty sand
15	20	303	3/4" gray clayey silty sand over reddish-brown clayey silty sand
16	25	340	Soft pink-brown clay with 1 cm gray patches
18	30	420	1/8" brownish-gray silt over 1" black gritless silt over 3/4" brownish-gray soft clay over 3/4" gray soft clay over brownish-gray soft clay - all clay layers slightly sandy
17	35	420	1/4" gray silt over 1-1/2" sandy gray clay over softer red-brown sandy clay

Line XIX; bearing 90° from W. shore at Lake Forest, Illinois

Sample No.	Miles from Shore	Depth (feet)	Description
14	1	35	Gravel; up to 10 cm diameter
13	2	40	Gravel and coarse sand, few shells
12	3	47	Gravel and coarse sand, few shells, over compact gray sandy silty clay
11	4.1	55	Gravel (up to 12 cm) and coarse sand
10	5	68	Grayish-buff silty coarse sand, few pebbles, up to 8 cm diameter
9	6	77	Coarse sand, few pebbles up to 4 cm diameter
8	7.1	93	Gravel and very coarse sand; gravel up to 10 cm diameter
7	8.2	103	Gravel, up to 5 cm diameter
6	9	116	Grayish-buff silty fine sand
5	11.5	120	One cobble, 9 cm diameter, with black coating (organic?)
4	14	154	Grayish-buff silty fine-to-coarse sand, few small pebbles (to 1 cm)
3	16	178	Grayish-buff silty fine-to-coarse sand, few pebbles (to 5 cm)
2	18	214	Grayish-brown clayey silty sand over brownish-red silty sandy clay
1	20	245	Grayish-brown clayey silty sand
15	25		1/4" gray layer at top over soft brown sandy clay
16	30	335	1/8" brownish-gray silt over 2" reddish-brown soft sandy clay over firmer gray sandy clay
17	35	350	Thin covering brownish-gray silt over soft very-slightly-sandy pink-brown soft clay

Line XX; bearing 90° from W. shore near Glencoe, Illinois,
to buoy, 8 miles then 85° from buoy

Sample No.	Miles from Shore	Depth (feet)	Descriptions
1	2	40	Gravel
2	3	47	Gravel
3	4	50	1 granule in 3 trials
4	5	55	Gravel
5	6	58	1 pebble in 2 trials
6	7	66	Gravel (including angular block 20 cm long, limestone and chert)
7*	8	45	Few grains coarse sand and gravel
8	9	104	1st trial: few sand grains 2nd trial: coarse sand, poorly sorted
9	10	106	Coarse sand and fine gravel
10	12	140	Grayish-buff silty fine sand
11	14	163	Grayish-buff slightly silty medium sand
12	16	180	Grayish-buff silty medium-fine sand, very few small pebbles
13	18	213	Reddish-brown clayey silty sand, few small pebbles
14	20	265	1" brownish-gray sandy silty clay over sandy silty clay mottled reddish-brown and brownish-gray
15	25		1/4" sandy gray silt over reddish-brown soft slightly-sandy clay

*100 yds. N. of buoy

Line XXI; bearing 85° from W. shore at Wilmette

Sample No.	Miles from Shore	Depth (feet)	Description
14	2	38	No sample (rock bottom?)
13	3	43	1 cobble, 25 cm long
12	4	48	Gravel
11	5	66	1/4" dark gray sandy silty clay over medium sand and fine gravel
10	6	48	Medium-coarse sand and fine gravel
9	7	78	Coarse sand and fine gravel
8	8	90	Coarse sand and gravel (1 pebble, 5 cm long)
7	9	106	Gravel, and rusty-oxide crust on till-like material
6	10	118	Medium-coarse sand, gravel
5	12	137	Grayish-buff slightly silty fine-medium sand
4	14	162	Grayish-buff slightly silty fine-medium sand
3	16	200	3/4" gray silty fine sand over grayish-buff silty fine sand
2	18	217	1-1/2" brownish-gray sandy silty clay over sandy silty clay mottled reddish-brown and brownish-gray
1	20	228	1-1/2" brownish-gray sandy silty clay over sandy silty clay mottled reddish-brown and brownish-gray

Line XXII; bearing 79° from Wilson Avenue Crib, off
Montrose Harbor

Sample No.	Miles from Shore	Depth (feet)	Description
1*	2	42	Sand, gravel, few shells
2	3.1	41	Medium-fine sand, few granules, very few shells
3	4	48	1-1/4" medium-coarse sand and fine gravel over gray clay
4	5		1-1/4" medium-coarse sand and fine gravel over gray clay
5	6		Gravel, up to 7 cm diameter, small amount sand
6	7	75	Gravel, up to 5 cm diameter, small amount sand, very few shells
7	8	81	Medium-coarse sand and fine gravel
8	9	86	Medium-fine sand, few granules
9	10	100	Fine gravel
10	12	120	Very coarse sand
11	14	135	Grayish-buff slightly-silty medium-fine sand
12	16	151	Grayish-buff slightly-silty fine sand, few granules
13	18	166	Grayish-buff slightly-silty fine sand, few granules
14	20	184	3/4" brownish-gray silty fine sand over slightly-sandy red clay, with few shells
B-1	18.5	159	Grayish-buff slightly-silty fine sand
B-2	17.0	135	Gravel

*Wilson Avenue Crib

Line XXIII; bearing 75° from N.E. corner outer breakwater,
Chicago Harbor

Sample No.	Miles from Breakwater	Depth (feet)	Description
1	1	38	Coarse sand, gravel
2	2	45	Medium-fine sand
3	3	46	Gravel, over gray clay
4	4	47	Medium-fine sand
5	5	58	Very coarse sand, gravel, pieces of ceramic tile
6	6	67	Gravel, cinders, rusty nails; over stiff gray clay
7	7	67	Medium sand with few cinders
8	8	67	Sand and pebbles over stiff gray clay
9	9	80	Medium-coarse sand
10	10	88	Gravel over soft grayish-brown clay
11	12	109	Medium-fine sand
12	14	126	Medium-fine sand
13	16	139	Coarse sand and gravel
14	18	152	Coarse sand and gravel
15	20	166	Brown slightly-silty fine sand

Line XXIV; from offshore, 255°, to shore at Oakland Shoal

Sample No.	Miles from Shore	Depth (feet)	Description
15	1	31	Fine sand over gray clayey fine sand
14	2	35	Medium sand
13	3	39	Fine sand over stiff gray clay
12	4	45	Silty coarse sand and granules
11	5	50	Gravel over gray stiff sandy clay
10	6	45	Medium-fine sand over stiff gray clay
9	7	58	Medium-fine sand
8	8	60	Coarse sand, few pebbles
7	9	57	Medium-fine sand
6	10	75	Gravel, over gray stiff sandy clay
5	12	87	Well-sorted gravel, mainly fine
4	14	97	Medium sand
3	16	110	Gravel, over gray stiff sandy clay
2	18	120	Medium-coarse sand
1	20	128	Gravel

Line XXV; bearing 70° from Calumet Harbor

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	33	Gravel over gray stiff sandy clay (Foul odor.)
2	2	40	Medium sand
3	3	44	Gravel over gray stiff sandy gravelly clay (till?)
4	4	43	Coarse sand, few pebbles
5	5	45	Medium-coarse sand, few granules and pebbles
6	6	47	Gravel over gray stiff sandy gravelly clay (till?)
7	7	46	Medium-fine sand
8	8	43	Medium-fine sand
9	9	67	Slightly-silty fine sand
10	10	72	Gravel
11	12	66	Gravel, over stiff gray clay
12	14	86	Gravel and coarse sand over stiff gray clay
13	16	100	Gravel, over gray stiff sandy gravelly clay (till?)
14	18	98	Grayish-brown slightly-silty fine sand
15	20	107	Grayish-brown slightly-silty fine sand

Line XXVI; from offshore, 240°, to Indiana Harbor

Sample No.	Miles from Shore	Depth (feet)	Description
13	1	35	Medium-fine sand, few small pebbles
12	2	35	Gravel
11	3	30	Medium-coarse sand, few granules
10	4	38	Medium-fine sand
9	5	40	Fine sand
8	6	56	Fine sand with some organic matter, cinders, wood. Odor of oil
7	7	56	Mottled gray and brown silty fine sand. Odor of oil
6	8	66	Mottled gray and brown silty fine sand. Odor of oil
5	9	65	Medium-fine sand
4	10	70	Gravel over gray stiff sandy clay
3	12	67	Fine sand
2	14	91	Gray soft clayey sand over stiff gray clay
1	16	90	Medium sand

Line XXVII; bearing 0° (N) from Gary, Indiana

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	47	Fine sand, with very coarse sand-size fragments of Antrim Shale
2	2	58	Silty very fine sand
3	3	53	Fine sand, with coarse sand-size fragments of Antrim Shale
4	4	53	Fine sand, with coarse sand-size fragments of Antrim Shale
5	5	48	Coarse sand
6	6	56	Coarse sand. Odor of oil
7	7	58	Dark gray silty very fine sand with some vegetable matter. Strong odor of oil
8	8	52	Medium sand, with few coarse sand-size fragments of Antrim Shale
9	9	61	Medium-fine sand with few fragments of Antrim Shale
10	10	66	Fine gravel, mainly well-sorted. (Median diameter about 3 mm)

Line XXVIII; bearing 0° (N) from Burns Ditch

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	38	Medium sand
2	2	45	Fine sand
3	3	46	Gravel, over gray stiff clay
4	4	47	Fine sand
5	5	58	Coarse sand - fine gravel over gray silty very fine sand. Odor of oil
6	6	67	Gray slightly-silty fine sand
7	7	67	Medium-coarse sand, over stiff gray clay
8	8	67	Medium-coarse sand
9	9	80	Medium-coarse sand, few pebbles, over soft gray clay
10	10	88	Silty medium-fine sand over stiff gray clay
11	12	109	Gravel and coarse sand
12	14	126	Gravel
13	16	139	Fine sand, with few granules, over gray stiff sandy clay
14	18	152	Silty very fine sand, with few small pebbles
15	20	166	Slightly-silty medium-coarse sand, with few granules

Line XXIX from offshore, 150°, to Michigan City, Indiana

Sample No.	Miles from Shore	Depth (feet)	Description
15	1	57	Coarse sand
14	2	58	Medium sand
13	3	60	Medium-fine sand, over soft gray clay
12	4	65	Fine sand
11	5	77	Gray silty very fine sand
10	6	80	Gray silty very fine sand
9	7	90	Grayish brown silty medium-fine sand
8	8	104	Grayish brown silty medium-fine sand
7	9	113	Grayish brown silty medium-fine sand
6	10	125	Grayish brown silty medium-fine sand
5	12	140	Grayish brown silty medium-fine sand
4	14	155	Grayish brown silty medium-fine sand
3	16	168	Grayish brown silty medium-fine sand
2	18	183	Gray-brown soft clayey silty fine sand over brownish-buff firm clayey silty fine sand
1	20	190	Gray-brown soft clayey silty fine sand over brownish-buff firm clayey silty fine sand
16	31-1/2		1/2" gray sandy silt over 1-1/2" brown-buff sandy silt over sandy soft red clay

Line XXX; bearing 320° from shore at New Buffalo, Michigan

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	47	Medium-fine sand
2	2	55	Medium-fine sand, few granules
3	3	66	Medium-fine sand, over dark gray clayey sand
4	4	66	Medium sand
5	5	83	Brownish-gray silty fine sand
6	6	95	Brownish-gray silty very fine sand
7	7	107	Brownish-gray silty very fine sand, few medium sand grains
8	8	121	Brownish-gray silty very fine sand, few medium sand grains
9	9	136	Gray very-fine-sandy silt
10	10	149	Gray very-fine-sandy silt
11	12	175	Gray very-fine-sandy silt
12	14	197	Gray very-fine-sandy clayey silt
13	16	218	Gray sandy silty clay
14	18	235	Gray sandy silty clay
15	20	244	Gray sandy silty clay

Line XXXI from offshore, 135°, to shore near Sawyer, Mich.

Sample No.	Miles from Shore	Depth (feet)	Description	
15	1	54	Medium sand over light brownish-gray silty medium-fine sand	
14	2	57	Medium-fine sand	
13	3	67	Fine sand over light brownish-gray silty fine sand	
12	4	76	Medium sand	
11	5	87	Brown medium-fine sand over brownish-gray silty medium-fine sand	
10	6	97	Grayish-brown silty very fine sand	
9	7	115	Brownish-gray (brown at surface) very-fine-sandy silt	
8	8	140	Gray very-fine-sandy silt	
7	9	157	Brownish-gray slightly-sandy clayey silt	
6	10	173	Brownish-gray slightly-sandy clayey silt	
5	12	195	Brownish-gray slightly-sandy silty clay	<div> increasing clay per-centage </div>
4	14	222	Brownish-gray slightly-sandy silty clay with increasing clay percentage	
3	16	249	Brownish-gray slightly-sandy silty clay with increasing clay percentage	
2	18	267	Brownish-gray slightly-sandy silty clay with increasing clay percentage	
1	20	280	Brownish-gray slightly-sandy silty clay with smaller percentage of grayish-brown clay	
16	32 $\frac{1}{2}$		1/2" gray sandy silt over soft gritless reddish-tan clay	

Line XXXII; bearing 300° from shore near Grand Marais Lakes

Sample No.	Miles from Shore	Depth (feet)	Description
1	1	45	Medium-coarse sand
2	2	65	Medium-coarse sand
3	3	77	Medium-fine sand over brownish-gray silty fine sand
4	4	85	Grayish-brown silty very fine sand
5	5	100	Brownish-gray very-fine-sandy silt
6	6	124	Brownish-gray very-fine-sandy silt
7	7	153	Gray very-fine-sandy clayey silt
8	8	178	Gray clayey silt
9	9	198	Gray silty clay
10	10	215	Gray silty clay
11	12	240	Brownish-gray silty clay
12	14	268	Brownish-gray silty clay
13	16	298	Grayish-brown sandy silty clay over brownish-gray silty clay
14	18	312	Grayish-brown sandy silty clay over brownish-gray silty clay
15	20	327	Grayish-brown sandy silty clay over brownish-gray silty clay

Reference Stations

Ref. Station No.	Location	Depth (feet)	Description
I	5.7 miles off-shore. 3.0 miles, 117° from Four Mile Crib, Chicago	48	Medium sand, few granules (clean)
II	19.3 miles off-shore. 17.1 miles, 55° from Four Mile Crib, Chicago	173	3/4" buff-gray slightly-silty fine-to-very-fine sand over 1-1/2" buff-gray silty fine-very-fine sand over brownish-buff clayey silty fine-very-fine sand with small pebbles. (all layers contain a few small shells)
Mid-way between II and III			1/4"-1/2" gritless gray silt over buff sandy clay
III	30 miles off-shore. 29.5 miles, 292° from Benton Harbor pierhead (D. R. position)	(340±)	Red clay. (Core sample 90 cm long; viewed through plastic liner, appears fine-grained and uniform for entire length)
Mid-way between III and IV			1/4" gray sandy silt over 1/8" buff silty fine sand over soft gray clay
IV	34 miles off-shore. 34 miles, 292° from South Haven pierhead (D. R. position)	(470+)	Gray clay. (Core sample 90 cm long; viewed through plastic liner, shows color bands of light gray and black, entire length)

Sample No.	Location	Depth (feet)	Description
63-1	Chicago Outer Light 42°10', 87°20'	237	1/4" gray slightly-sandy silty clay over red clay
63-2	2 mi 039° from 63-1	248	1/2" gray slightly-sandy silty clay over grayish- buff sandy silty clay
63-3	2 mi 039° from 63-2	261	1/2" gray slightly-sandy silty clay over grayish- buff sandy silty clay
63-5	4 mi 039° from 63-3	282	Soft red clay
63-6	2 mi 039° from 63-5	295	Gray silty clay
63-7	2 mi 039° from 63-6	307	Gray silty clay
63-8	2 mi 039° from 63-7	327	Gray silty clay
63-20	42°00' N., 87°00' W.	525	Dark gray clay
63-21	42°00' N., 87°00' W.	525	Dark gray clay
63-22	2.8 mi 015° from 63-21	527	Dark gray clay
63-23	2.8 mi 015° from 63-22	508	Dark gray clay
63-25	5.6 mi 015° from 63-23	376	Dark gray clay
63-26	2.1 mi 069° from 63-25	340	Dark gray clay
63-27	2.1 mi 069° from 63-26	325	Dark gray clay
63-28	2.1 mi 069° from 63-27	307	Dark gray clay

STUDIES ON WATER MOVEMENTS AND SEDIMENTS IN
SOUTHERN LAKE MICHIGAN

Part III. Current Studies and Supplemental
Sediment Studies

John C. Ayers
Frank R. Bellaire

ORA Project 05466

Part III (Last Part) of the Final Report of
H.E.W. Contract PH-86-63-60

GREAT LAKES RESEARCH DIVISION
Special Report No. 19

INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

July 1964

ERRATA, PART I OF FINAL REPORT

The section made on 24 June 1963 contained one leg which ran north-south; across this leg the transport was parallel to the sill and should not be considered as entering either basin. This transport ($1208 \text{ m}^3/\text{sec}$ south) was removed in the detailed presentation on page 39, but was not subtracted in the summary on page 5. The following corrections should be made:

p 5, line 8: substitute 2,675 for 3,883

line 10: substitute 54,971 for 56,179

p 13, line 8 from bottom: substitute 2,700 for 3,800
and substitute 0.10 for 0.13

line 7 from bottom: substitute 0.11 for 0.14

line 6 from bottom: substitute 4182 for 3286,
and substitute 4840 for 3803

line 3 from bottom: substitute $1/4840$ for $1/3803$

line 2 from bottom: substitute 0.00020 for 0.00026

p 14, line 1: substitute -0.00020 for -0.00026 in the
exponent

line 2: substitute -0.00020 for -0.00026

line 3: substitute 23,025 for 17,712 and 63.1
for 48.5

line 8: substitute 34 for 26

p 16, line 7 from bottom: substitute 34 for 26

line 2 from bottom: substitute "about" for "only"

p 17, line 10: substitute 2,700 for 3,900

PREFACE TO THE ENTIRE REPORT

Several factors have dictated that this final report should be in separate parts.

The contract covered studies of different sorts. By the nature of the studies, the times required for work-up and analysis of data have varied widely, some parts being completed long before others could be finished. The different studies have required greatly varying amounts of ship-time and some, which required unexpectedly large amounts of ship-time, are being augmented by data obtained during cruises for other projects when vessels are in suitable regions. Finally, it is believed that assimilation by the reader is aided by brevity and unit reporting.

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INTRODUCTION TO PART III

This last portion of the final report on work performed under the contract includes a number of related studies carried out since the expiration of the contract. These related studies are in part studies that required more time than had been allowed under the contract; in part they are extensions of studies originally reported; and in part they are new studies not actually a part of the contract but which cover items known to be within the interest area of the USPHS Great Lakes-Illinois River Basin Project.

This report presents in final form the work done on current determination by "standard" methods at USPHS anchored buoy systems to enable cross-comparison of methods by USPHS.

It presents in final form the work done on the development and evaluation of radio-bearing current drogues as means for following currents for extended periods of time.

A limited amount of data on the annual regime of vertical temperature distribution in the waters off Chicago is included. These data were assembled and studied to ascertain whether density stratification in the local water-column was apt to result in a two-layered system in which bottom currents might be differently directed than the surface currents.

In two cases data obtained for other purposes have been suitable for crude estimates of the dilution rate inherent in the waters off Chicago.

The areal extent of the oily sediments off Gary, Indiana, (previously reported) has been determined and their probable

origin at least temporarily decided upon. A similar area off Milwaukee has been found.

A survey of the sediments of Milwaukee Embayment has been carried out with the discovery of pronounced eutrophic changes in sediment characteristics within Milwaukee Harbor. These are reported in preliminary form.

Two portions of the work originally proposed could not be carried out.

1. A magnetometer could not be obtained, and the planned start on the determination of the magnetic anomalies of the southern basin of Lake Michigan could not be carried out.
2. Despite our best efforts we were unable to devise a current drogue that could be found after long periods and which still had so little windage effect that it would stay within the water-mass in which it was set. Consequently we were unable to achieve a study of the attrition of water masses.

Survey of the substructure of the basin of lower Lake Michigan by the sparking sub-bottom profiler was deliberately abandoned because the reduced ship-speed that it required would have used excessive amounts of ship-time. To have obtained even an incomplete sparker survey would have prevented the completion of the bottom sediment survey reported in Part II of this Final Report.

METHODS

Currents were determined by current drogue and by the dynamic height method of Ayers (1956) and Ayers and Bachmann (1957). Both these methods were used in part of the studies at USPHS anchored buoy systems; in others drogues alone were used.

Small citizens-band (ten-meter) radio transmitters were developed and used successfully for drogue drifts up to three days. The transmitters developed (Model ERC 127A manufactured by Electronic Research Corporation of Ann Arbor) were crystal-controlled at separate frequencies within the citizens band and emitted an unmodulated carrier transmission which was rendered audible by the beat frequency oscillator of the receiver, a Hammerlund Model HQ-180 all-band receiver. In use, the transmitters were wrapped in plastic sheet and lashed into the radar reflectors of the drogues.

Two 10-meter yagi antennae were mounted vertically on the yardarm of the ship's aftermast for reception of signals from the drogue transmitters. This antenna arrangement provided a strong lobe of reception from ahead of the ship and a weak lobe from aft; reception from abeam was almost nil. Under good conditions the drogues could be heard from about 15 miles ahead. The ship was "homed" aurally on the greatest strength of signal until radar contact was made.

Except where specifically noted, surface drogues used in these studies were influenced by the top 7-1/2 feet of the water. Except off Chicago, where depth was limited, deep

drogues were customarily set with their current drags beneath the thermocline.

Navigation during these studies was in large part by sextant fixes or radar fixes. In a few cases it was necessary to navigate by dead-reckoning.

RESULTS

Current Studies

Studies in the Chicago Region

Our studies in the Chicago region were in large part centered around $41^{\circ}50.0'$ N, $87^{\circ}30.0'$ W near the site of the diffuser proposed by the lakes states in the recent Chicago litigation. Their primary purpose was to provide information on the direction of currents under various winds.

Drogue run, 28 April 1963 (Fig. 1): A surface drogue and a 44-foot drogue were set at $41^{\circ}50.6'$, $87^{\circ}29.5'$. The deep drogue apparently went aground promptly, for it made no movement in two-plus hours. It is not shown in Figure 1.

The surface drogue moved due west a distance of 3200 feet in 2 hours 16 minutes, giving an indicated current velocity of 0.27 mph.

The wind regime of the 26th through the 28th was:

26 Apr.		E	10-12 knots
27 Apr.	AM	SE	7 k
	PM	NE	13 k
28 Apr.	AM	SE	10 k
	PM	ENE	15 k

Drogue run, 4-7 June 1963 (Fig. 2): Four radio drogues were set near the diffuser site on 4 June. During 5 June, while the ship was detained in Chicago harbor, the drogues could be heard distinctly. During the position fixing of 6 June and the recoveries on 7 June the ship homed on the drogues by radio and found them readily.

Drogues I and II were set at 0804, but drogue I (set for 43 feet in charted depths of 48 feet) did not move and was

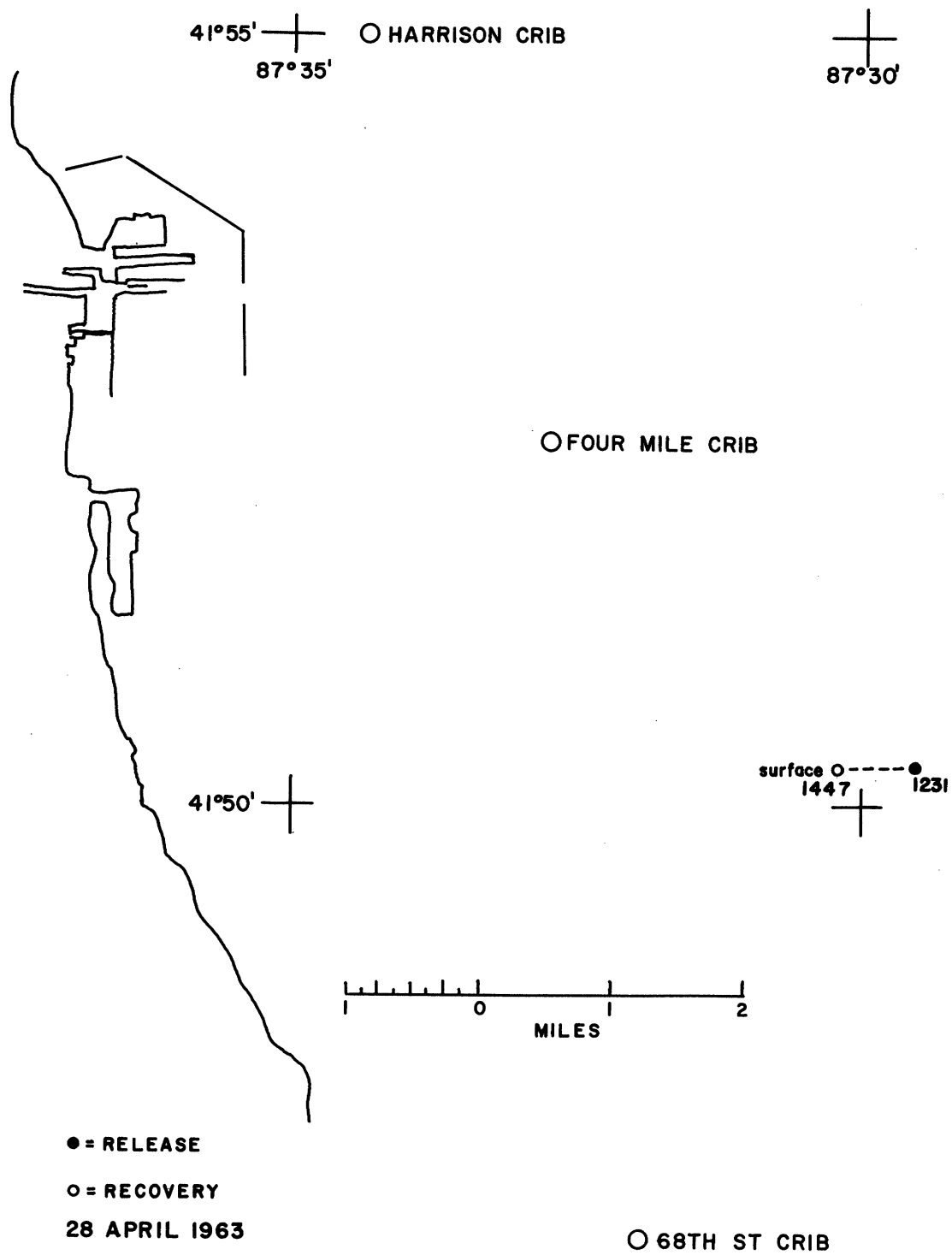


Figure 1

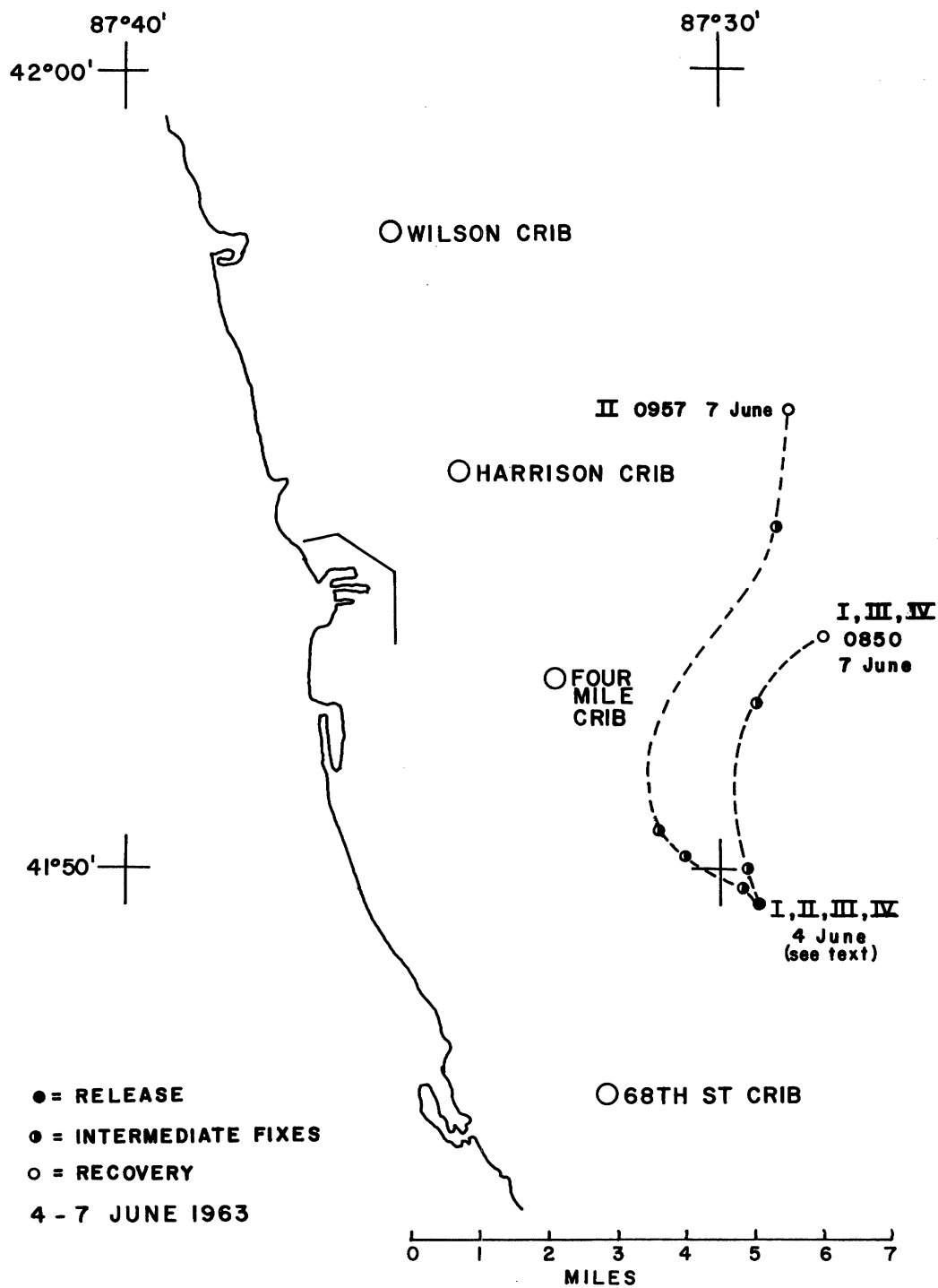


Figure 2

obviously aground from the time of setting. Drogue II (surface drogue) moved off toward the northwest immediately after setting.

At 1320 drogues III (22 feet) and IV (surface) were set alongside drogue I. Drogue I was lifted briefly, ten feet of suspension wire removed, and reset. When set at 33 feet drogue I did not go aground.

At 1320 drogues I, III, and IV were in a circle of about 50 feet diameter. At recovery on 7 June they were still together in a circle of about 200 feet diameter.

Drogue II, set earlier than the other three, maintained a separate course throughout the three days. It travelled an apparent 8.2 miles during its 73.9 hours adrift, giving an indicated speed of 0.11 mph.

Drogues I, III, and IV travelled an apparent 4.3 miles during their 67.5 hours adrift, giving an indicated speed of 0.06 mph.

The chronology of positions plotted in Figure 2 was:

4 June	0804	#II	41°49.6', 87°29.4'	(set)
	0927	#II	41°49.8', 87°29.7'	
	1300	#II	41°50.2', 87°30.7'	
	1320	#I, III, IV	41°49.6', 87°29.4'	(set)
	1645	#I, III, IV	41°50.0', 87°29.6'	
	1650	#II	41°50.4', 87°31.0'	
6 June	1400	#I, III, IV	41°52.1', 87°29.4'	
	1432	#II	41°54.2', 87°29.0'	
7 June	0850	#I, III, IV	41°52.9', 87°28.3'	(recovery)
	0957	#II	41°55.7', 87°28.8'	(recovery)

The wind during this period was:

3 June	S	4 - 8 knots	
4 June	NW 6 k to NE 5-12 k		{W during the night}
5 June	light sea breeze		{W during the night}
6 June	SW to SE 4 k to SW		{turned N during the night}
7 June	N 8-10 k		

Drogue run, 20-21 June 1963 (Fig. 3): This was a radio drogue run, carried out under severe conditions to assess the sturdiness of the drogue radio transmitters.

During the evening of 19 June a severe squall and frontal passage occurred at Chicago. During and after the frontal passage winds up to fifty knots were reported. During the night of the 19th the wind slowly tapered off, but large seas were built up. Wind and seas slowly moderated during the 20th and 21st.

At 1420 on 20 June two radio drogues, #II at 20 feet and #IV at the surface, were set at $41^{\circ}50.1'$, $87^{\circ}29.5'$. At the time of setting the wind was from the north at 16 knots and seas estimated to be six feet high were running.

After returning to Chicago harbor, the drogue transmitters were heard still functioning at 1620 and at 1820.

On 21 June search for the drogues was carried out under winds of 7-10 knots and in 3-4 foot seas. At this time drogue IV was transmitting a weak and fuzzy signal that was homed on with difficulty but which did lead us to the drogue. Recovery was made at 1217 just outside Indiana harbor at $41^{\circ}42.2'$, $87^{\circ}26.3'$.

Inspection of the recovered drogue showed that the transmitter's whip antenna had broken off; the transmission heard was from a stub of the antenna-feed wire.

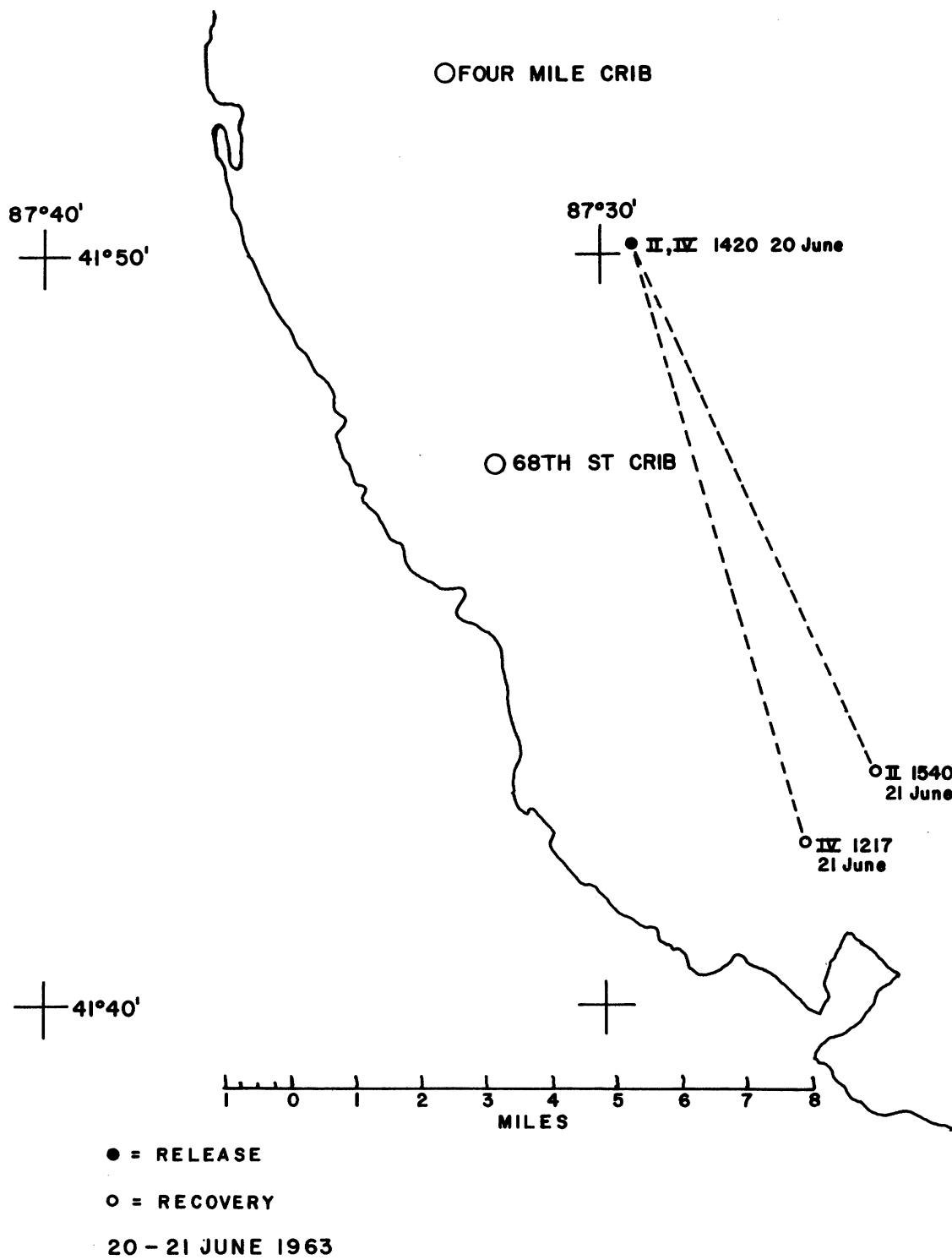


Figure 3

No transmission from drogue #II was heard on 21 June. By blind hunting (sea-return rendered the radar almost useless) the drogue was found outside Indiana harbor. Recovery was made at 1540 at $41^{\circ}43.0'$, $87^{\circ}25.2'$. The antenna of this transmitter had also broken off and had pulled the feed-wire out with it.

After this day antenna break-off was prevented by taping a slender wooden block between the antenna and the drogue-staff top.

Drogue II had travelled an apparent 8.8 miles in 25.3 hours, going an indicated speed of 0.35 mph. Drogue IV travelled an apparent 9.5 miles during 21.95 hours, an indicated speed of 0.43 mph.

Drogue run, 4-5 October 1963 (Fig. 4): This run was without radios; the drogues were hunted by radar and positioned by sextant fixes.

Surface drogues I, II, and III, plus drogues IV and V (both at 36 feet) were set at $41^{\circ}51.2'$, $87^{\circ}29.0'$ at 1227 on 4 October.

Drogues IV and V moved 700 feet west in the interval between 1227 and 1800 when they were taken up. Drogue V showed evidences of hitting bottom (bends and gouges on the lower edge of the sheet metal drag). Drogue IV stayed with V during the entire period, but did not show evidence of hard grounding. Because grounding may have hindered the movement of these two drogues, they are considered suspect.

Drogues I, II, and III retained the same relative positions throughout the period of drift. At setting I and III were each about 50 feet from II. At 1730, when II was fixed, I and III

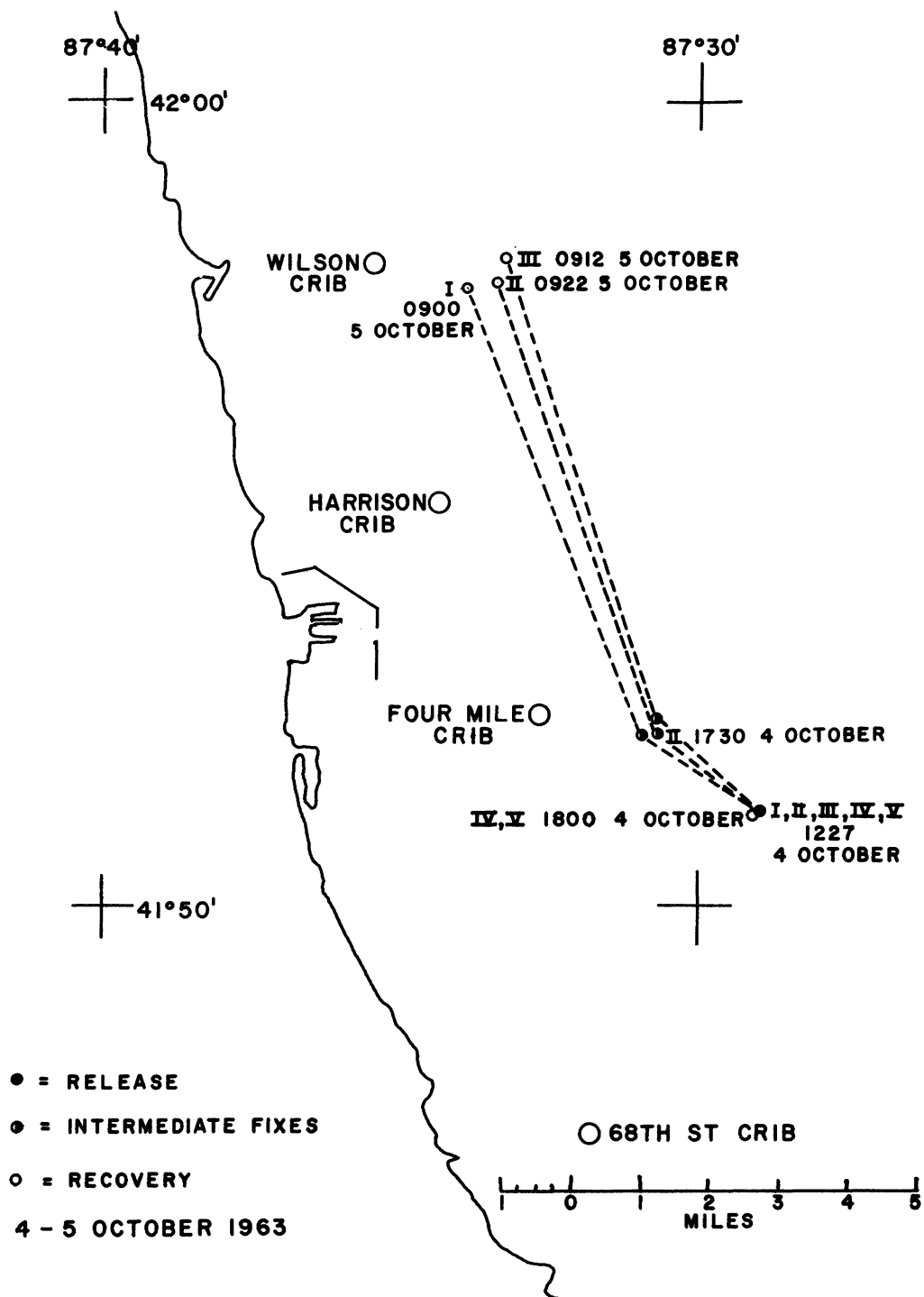


Figure 4

were estimated to be each about a quarter mile from II. At recovery on 5 October I was, by fix, 2500 feet from II and III was 2000 feet from II.

Drogue I travelled an apparent 9.2 miles during 20.55 hours--an indicated speed of 0.45 mph. Drogue II travelled an apparent 8.8 miles during 20.9 hours, for an indicated speed of 0.42 mph. Drogue III travelled an apparent 9.0 miles in 20.75 hours, giving an indicated speed of over 0.43 mph.

The chronology of fixes during this run was:

4 Oct.	1227	#I, II, III, IV, V	41°51.2', 87°29.0' (set)
	1730	#II	41°52.2', 87°30.8' (fix)
		#I	41°52.2', 87°31.0' (estimated)
		#III	41°52.3', 87°30.8' (estimated)
5 Oct.	0900	#I	41°57.6', 87°33.9' (fix) (recovery)
	0912	#III	41°58.1', 87°33.3' (fix) (recovery)
	0922	#II	41°57.7', 87°33.4' (fix) (recovery)

The wind regime for this run was:

3 Oct.	NW	20 knots (on east side of lake)
4 Oct.	SE	10-12 k
5 Oct.	S	10 k (becoming 14 k later in day)

Drogue run, 9-10 October 1963 (Fig. 5): This run involved one radio drogue (IV) that was used to home the ship into radar range.

Drogues II, III, IV, and V were set at 0920 on 9 October; setting position, by radar fix, was 41°51.5', 87°29.3'. Drogues III and IV were normal surface drogues, each carrying a single sheet metal drag; drogue II carried two current drags in tandem. This configuration of drags was a test (reported later) to ascertain whether windage on the drogue floats was significant.

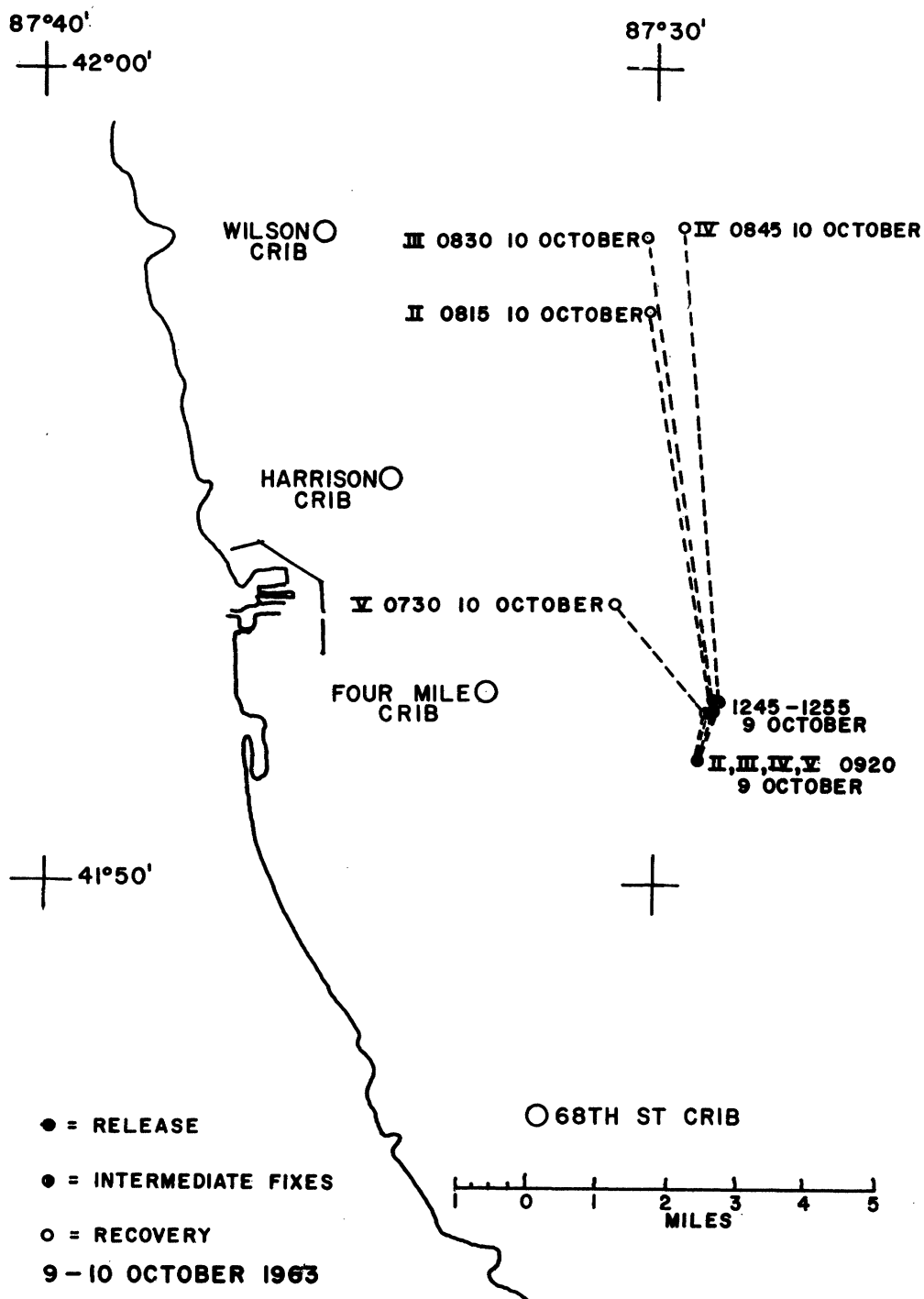


Figure 5

Drogue V was set at 36 feet; upon recovery it showed evidence of grounding. Its direction of movement and its rate of movement are suspect.

Drogues II, III, and IV retained the same relative positions during the drift. Set about 50 feet apart, the intervals between them had opened to about 1/8th mile by 1245-1255 on the 9th. At recovery IV was a half mile from III and II was a mile behind III.

Drogue II moved an apparent 6.7 miles in 22.9 hours--an indicated speed of 0.29 mph. Drogue III travelled an apparent 7.8 miles in 23.2 hours for an indicated speed of 0.34 mph. Drogue IV drifted an apparent 7.9 miles during 23.4 hours, giving an indicated speed of 0.34 mph.

The chronology of positions during this run was:

9 Oct. 0920 #II, III, IV, V 41°51.6', 87°29.3' (set, radar fix)
1245-1255 #II 41°52.2', 87°29.0' (sextant fix)
 #III 41°52.3', 87°29.0' (sextant fix)
 #IV 41°52.3', 87°28.9' (sextant fix)
 #V 41°52.2', 87°29.2' (sextant fix)
10 Oct. 0730 #V 41°53.5', 87°30.7' (recovery, sextant fix)
 0815 #II 41°57.0', 87°30.1' (recovery, sextant fix)
 0830 #III 41°57.9', 87°30.2' (recovery, sextant fix)
 0845 #IV 41°58.2', 87°29.6' (recovery, sextant fix)

The wind regime for this run was:

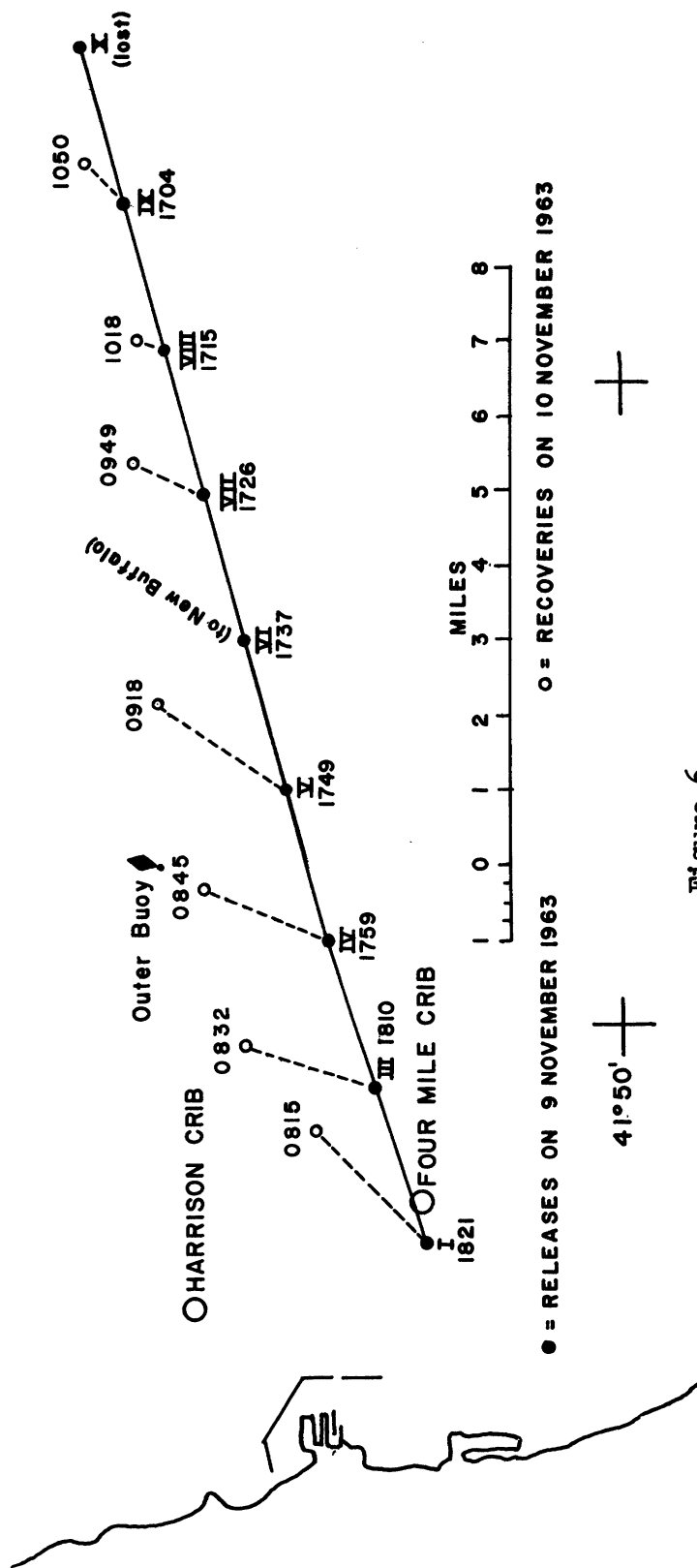
8 Oct. (evening) SE 4 knots
9 Oct. SSW 6-10 k
10 Oct. (early AM) SSE 12-20 k

Drogue run, 9-10 November 1963 (Fig. 6): This drogue run was carried out with all drogue floats being of low-windage

87°30'
42°00' +

87°20' +

OWILSON CRIB



41°50' +

+

Figure 6

fish-net-buoy style. In this float the flotation is furnished by a series of ovo-cylindrical floats of five inches diameter. These floats are strung on the float staff until the current drag is carried but only the upper end of the uppermost plastic float extends through the water surface. The exposed portion of the uppermost float, a portion of the staff six feet long by $5/8$ inch wide, and a $3/8$ inch mesh wire radar corner reflector one foot in each dimension are the total of surfaces exposed to wind. Total windage exposure is 200 square inches, which is countered by an underwater exposure of 32 square feet. The new float eliminates 70 square inches of exposure to wind in comparison to the old-style float that is described under "Tests of Windage Effects on Drogues."

On 9 November a line of nine surface drogues was set as the ship approached Chicago from the east side of the lake. Drogues were set at about 2-mile intervals along a course running about 250° true from about 17 miles outside Four Mile Crib to a half mile inside the crib. All release positions involved in this run were radar fixes.

Drogue X is believed to have sunk; we find no record that it had been checked for adequacy of flotation against its current drag, and it disappeared from radar contact before the ship arrived at the position for setting drogue IX.

Drogue VI parted from its current drag (hit by steamer?). The float was found by the police of New Buffalo, Michigan, on the beach there on the morning of 2 December.

The seven drogues recovered had all moved various distances northward and their movements had various degrees of eastward

components. The greatest total movement was near the west (in-shore) end of the line.

The positions of release on 9 November and recovery on 10 November, and indicated speeds of travel were:

<u>Drogue</u>	<u>Release</u>	<u>Recovery</u>		<u>Indicated Speed, mph</u>
I	41°52.3', 87°33.4'	41°53.7', 87°31.7'	SF*	0.15
III	41°52.9', 87°31.0'	41°54.4', 87°30.3'	SF	0.13
IV	41°53.4', 87°28.7'	41°54.8', 87°27.9'	SF	0.12
V	41°53.9', 87°26.4'	41°55.4', 87°25.0'	SF	0.14
VI	41°54.3', 87°24.0'	-----		----
VII	41°54.9', 87°21.7'	41°55.7', 87°21.2'	RF*	0.07
VIII	41°55.3', 87°19.5'	41°55.6', 87°19.3'	RF	0.02
IX	41°55.7', 87°17.2'	41°56.3', 87°16.6'	RF	0.04
X	41°56.2', 87°14.8'	-----		----

*SF = sextant fix

*RF = radar fix

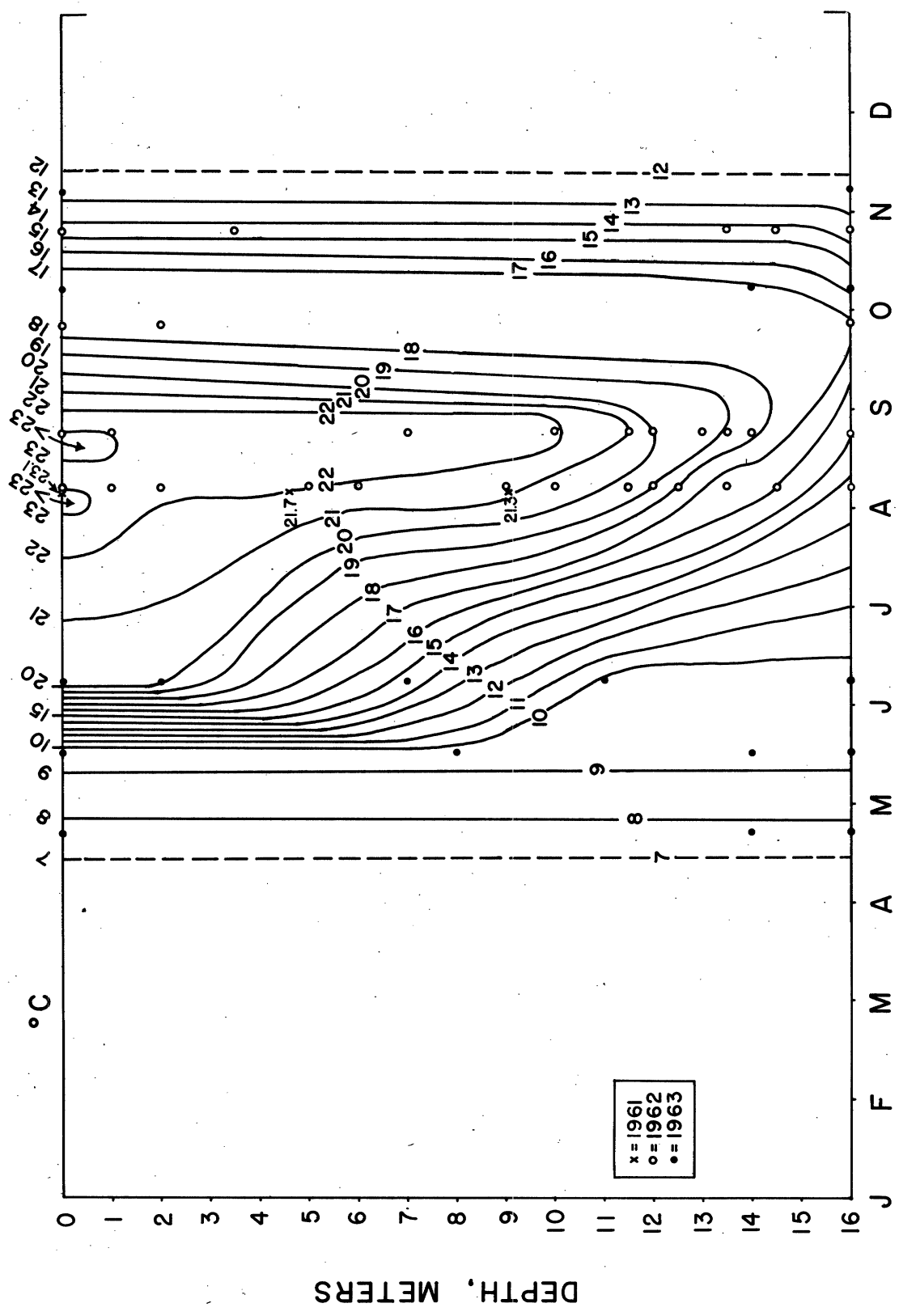
The wind regime pertaining to this run was:

8 Nov. NW 18-20 knots (over east side of lake)
 9 Nov. SSW 20 k (25 k further northeast in lake)
 10 Nov. NW 10-13 k (up to recovery time)

The Panorama of Temperature off Chicago

One of the factors that could bear upon the nature of currents in the waters immediately off Chicago is the local annual regimen of temperature. Study of temperature (density) structure off Chicago in the warmer parts of the year might show whether conditions conducive to two-layered current flow would develop.

Figure 7 presents a synthesized panorama of water temperatures near 41°50', 87°30' for the months April to November.



TEMPERATURE PANORAMA AT 41°50', 87°30' JUST OFF CHICAGO

Figure 7

Data from 1961 were from Chicago Outer Buoy; 1962 and 1963 data were taken at the diffuser position. The data of 1961 are reversing thermometer data; those of 1962 and 1963 are bathythermograph data. Dashed isotherms for 7° and 12° are estimates supported by data on only one side.

Figure 8, from Ayers (1962), has been provided to enable comparisons with deep-water conditions. A line indicating 16 meters of depth (the depth near the diffuser) has been drawn across this figure to aid in the assessment of depth as a factor in the local regimen.

As a test of the comparability of the years involved in Figures 7 and 8, (Chicago temperatures since 1960 being unavailable) we have compared the annual mean raw-water temperatures of the Milwaukee filtration plant for these years:

1941	7.06°C	1961	6.06°C
1942	6.56°C	1962	6.56°C
		1963	6.78°C

1941 and 1961 appear to have been somewhat warmer and cooler, respectively, than the other years, but 1942, 1962, and 1963 appear to be reasonably comparable. Since the latter three years comprise the bulk of both figures, comparisons between the figures seem justified.

Midsummer surface temperatures off Chicago attain higher values than those in the open lake. Both spring and fall temperatures are higher off Chicago than in midlake. More effective downward mixing of heat in spring is apparent off Chicago where the first isotherm to show a curvature indicative of developing stratification is that for 10° while in midlake the 5° isotherm develops a curvature above 16 meters, also in

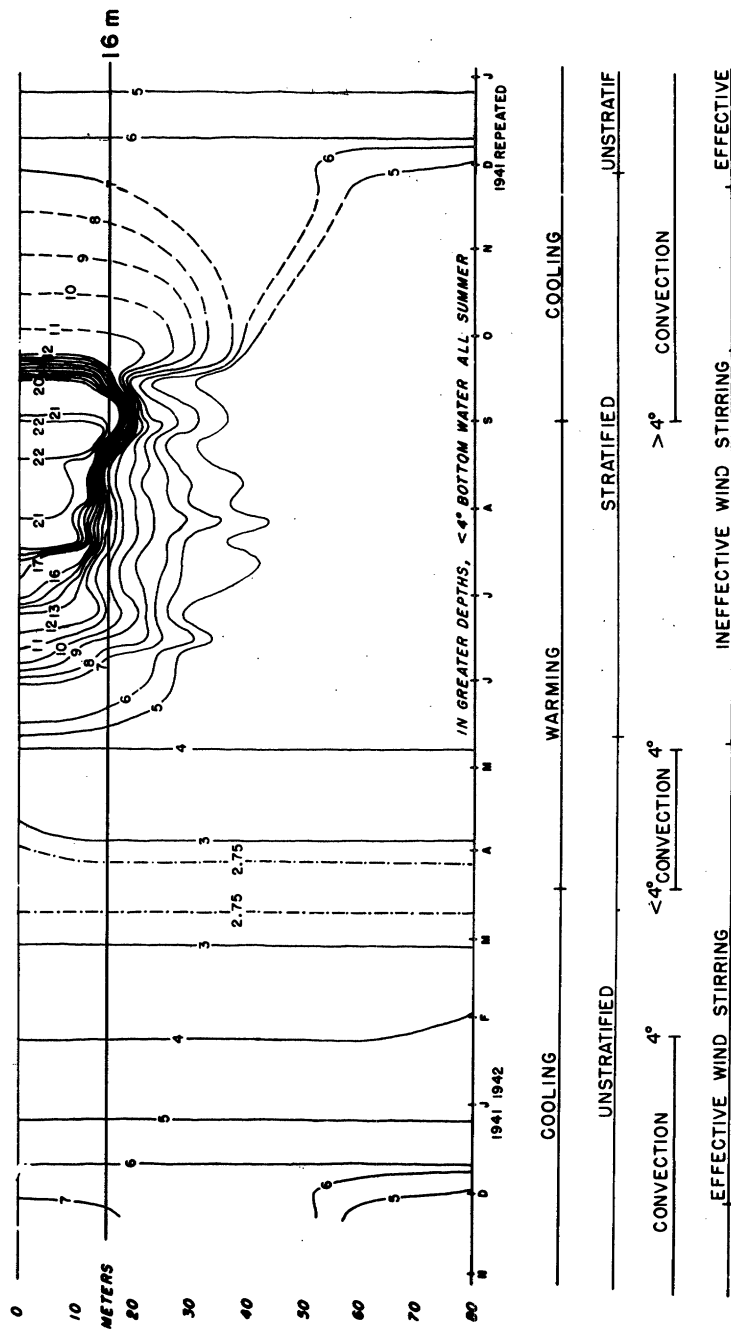


Figure 8

May. Off Chicago the most intense thermal and density stratification occurs in late August and involves only the upper isotherms of the lake's thermocline, the rest of the thermocline being intercepted by the bottom.

The bottom water off Chicago in the period of greatest stratification is mid-thermocline water; in the absence of internal waves typical two-layered flow is unlikely at this period.

In June a two-layered water column exists temporarily while the thermocline is developing but has not yet reached bottom; this appears to be the time of year when significant directional differences between surface and bottom currents (in the absence of internal wave activity) might occur if local development of a two-layered water column were the most important factor.

Internal wave activity, by tilting the thermocline and intruding colder subsurface water into the area, can establish temporary two-layered conditions with possible differences in top and bottom current directions regardless of the condition in the undisturbed local water column.

In the absence of internal waves the general condition off Chicago appears to be that surface and bottom currents would move in more or less the same direction during nearly all the year. The movements of the few successful deeper drogues off Chicago are in agreement with this conclusion.

Crude Estimates of Dilution off Chicago

While the drogue runs off Chicago were intended primarily

to give additional information as to the direction of current movement under different wind conditions, it has been possible to derive two crude estimates of the dilution rate inherent in the currents off Chicago. These estimates include error due to the windage effect on the drogue floats and are not considered to do more than indicate an order of magnitude.

The water off Chicago is relatively shallow and the bottom has but a gentle slope. The surface drogues of 4-5 October and of 9-10 October moved in relatively constant mean depths of 40 and 50 feet respectively.

If the two surface drogues farthest apart on these two occasions (Figs. 4 and 5) are considered to move along near the edges of an hypothetical plume of effluent originating at the bottom at the release position and extending upward through the water column, successive tentative cross-sectional areas of the plume can be computed.

Assuming that the progressive increases in cross-sectional area of the plumes are due to entrainment of diluting water from the environment, dilution can be expressed as ratios of plume cross-sectional areas at successive pairs of times. In constant depths the shape of the plume cross-section need not be known.

In the following, the width of the plume at the bottom at the origin is taken to be ten feet; its width at the surface at the origin is taken to be fifty feet (the distance apart of the drogues at setting). In the successive cross-sections the 5:1 ratio of plume width at surface to plume width at bottom is maintained (assumption of uniform dilution along the vertical

of the water column).

For the run of 4-5 October the separations of drogues I and III were: 50 feet at setting, and (by scaling from Fig. 4) 5/16 mile at 1730 on 4 October, and 7/10 mile at 0900-0912 on 5 October.

Keeping a five-to-one ratio of plume widths in constant mean depth of 40 feet, the successive plume cross-sectional areas are: 1200 ft^2 , 39600 ft^2 , and 88700 ft^2 . The successive ratios are: $39600/1200$ or 33X and $88700/39600$ or 2.2X. Crude estimate of total indicated dilution during the run: 33×2.2 or about 73X.

For the run of 9-10 October the distances apart of drogues III and IV were: 50 feet at setting, and (by scaling from Fig. 5) 1/8 mile at 1245-1255 on 9 October, and 1/2 mile at 0830-0845 on 10 October. With a five-to-one ratio of plume widths and in constant mean depth of 50 feet, the plume cross-section areas are: 1500 ft^2 , 19800 ft^2 , and 79200 ft^2 . The successive ratios of areas are: $19800/1500$ or 13.2X and $79200/19800$ or 4X. Crude estimate of total indicated dilution during the run: 13.2×4 or 52.8X.

Whether the plume cross-sections are considered to be rectangles of equal surface and bottom widths, as trapezoids of unequal surface and bottom widths, or as triangles with observed surface widths and zero bottom widths makes no difference; the same ratios of cross-sectional areas emerge.

Though crude, the indicated dilutions of less than 100X in a day mean a limited ability of the local currents to dilute introduced materials.

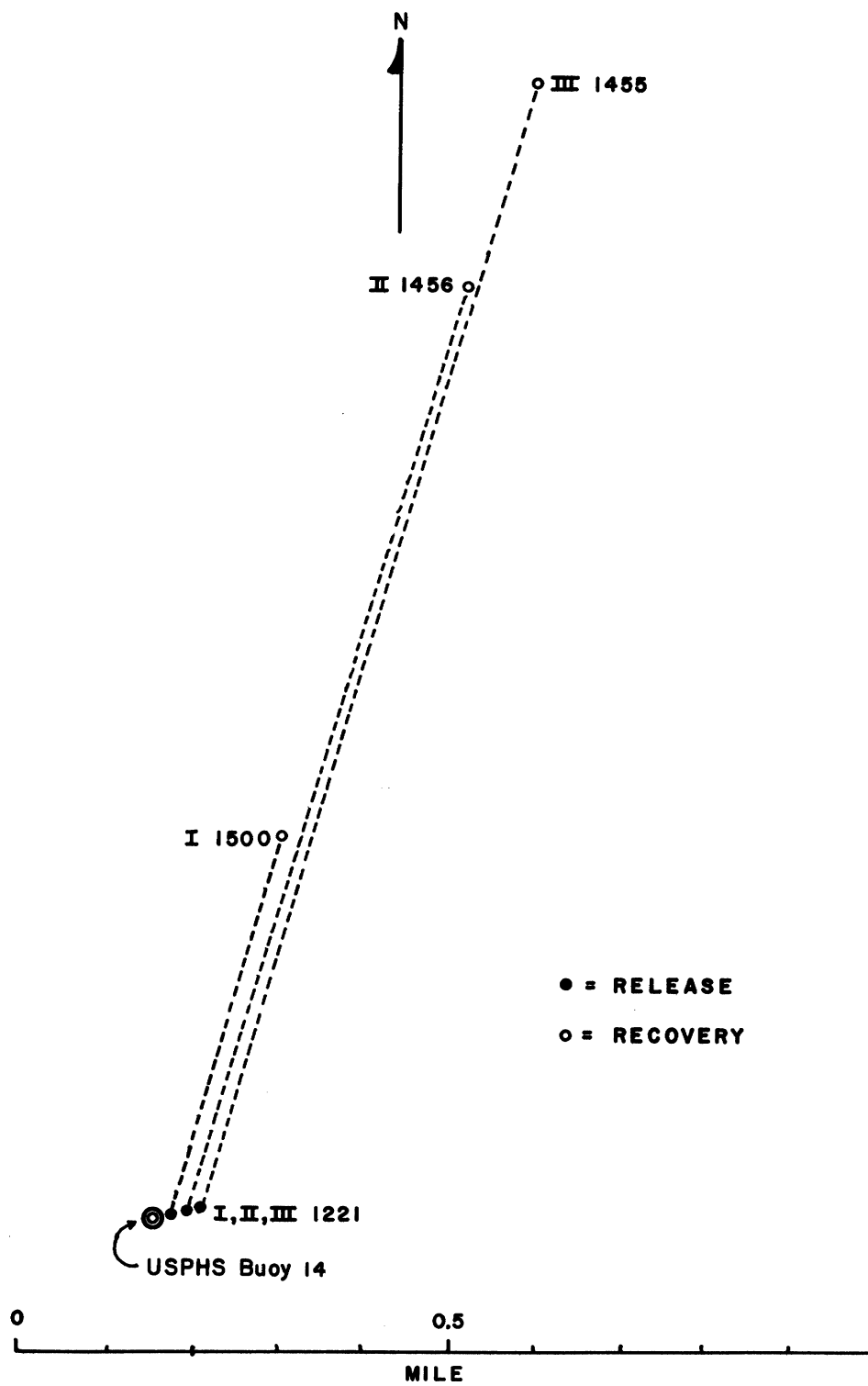
Studies at USPHS Buoy 14

BT and drogue run, 26 October 1963 (Figs. 9 and 10): On 26 October three drogues were set within a hundred yards of Buoy 14. Drogue I (130 feet) was set about 100 feet 075° true from the buoy; drogue II (tandem double drag, 0-12 feet) was set about 200 feet from the buoy on the same course; and drogue III (surface) was set about 300 feet from the buoy on the same course. The drogues were set (with the ship drifting rapidly) between 1220 and 1222; 1221 was accepted as the setting time of all three.

At recovery the drogues were all on a line bearing 018° true from the buoy. Recovery positions indicated are the positions of the drogues during a timed run along the line of their positions. After this run the ship returned and retrieved the drogues.

Drogue I had travelled an apparent 0.46 miles in 2 hours 39 minutes, giving an indicated speed of 0.17 mph for the current at 126-130 feet. Drogue II had moved an apparent 1.12 miles in 2 hours 35 minutes, indicating a speed of 0.43 mph. Drogue III covered an apparent 1.36 miles in 2 hours 34 minutes to indicate a velocity of 0.52 mph.

During the approach to the buoy, and after setting the drogues, the ship carried out a series of bathythermograph soundings on a course 098° true from a point 16 miles west of Buoy 14 to a point 12 miles east of the buoy. Figure 10 presents the components of current normal to the ship's course, as determined by dynamic heights computation. The curve for current components in the upper ten meters coincides with that for surface components over much of the figure; no attempt has



26 OCTOBER 1963

Figure 9

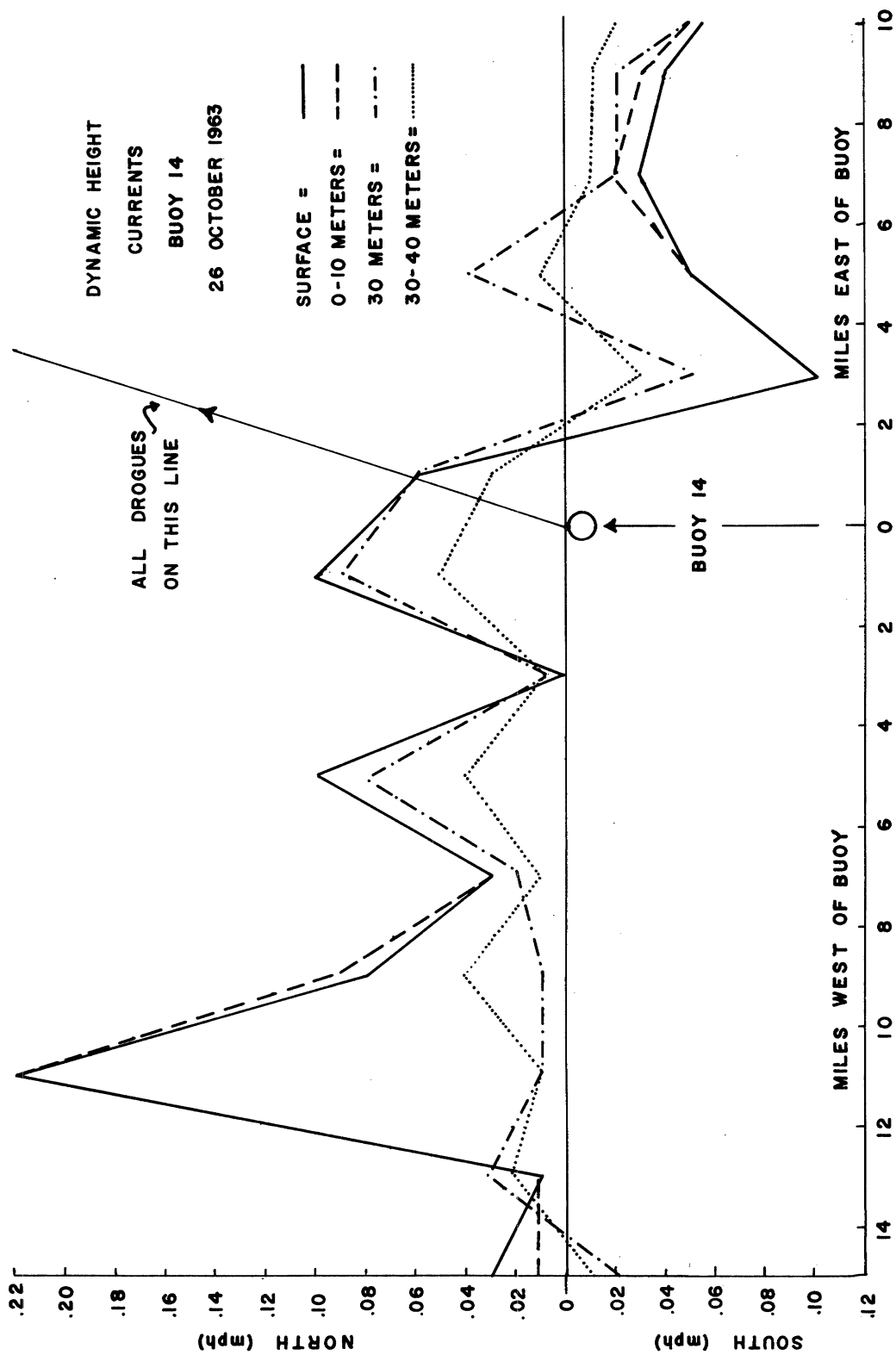


Figure 10

been made to indicate the superimposed portions.

Computed current direction changed from northward to southward about two miles east of the buoy. Major southward current was indicated between two and four miles east of the buoy. Major northward current was indicated to lie between 10 and 12 miles west of the buoy.

Current directions by dynamic height computation and by drogues were in agreement. Current velocity obtained by dynamic computation was 0.6 to 0.7 that given by the drogues.

The wind regime for this run was:

25 Oct.	SSW	8-12 knots
26 Oct.	S	13 k

Studies off Milwaukee

Drogue run, 24 October 1963, near USPHS Buoy 17 (Fig. 11):

On 24 October a surface drogue (IV) and a deep drogue (I, 70 feet) were set at 0923 and at 1040, respectively, near the position of USPHS Buoy 17. Positions were by sextant fix.

Drogue IV travelled an apparent 5.6 miles in 8 hours 25 minutes for an indicated speed of 0.67 mph.

Drogue I moved an apparent 2.8 miles during 7 hours 36 minutes, giving an indicated velocity of 0.37 mph at the 66-70 foot level.

The chronology of positions during this run was:

0923	#IV	43°07.6', 87°50.5'	(set)
1040	#I	43°07.8', 87°50.7'	(set)
1140	#IV	43°08.9', 87°51.0'	
1748	#IV	43°12.1', 87°52.4'	(recovery)
1816	#I	43°10.0', 87°51.5'	(recovery)

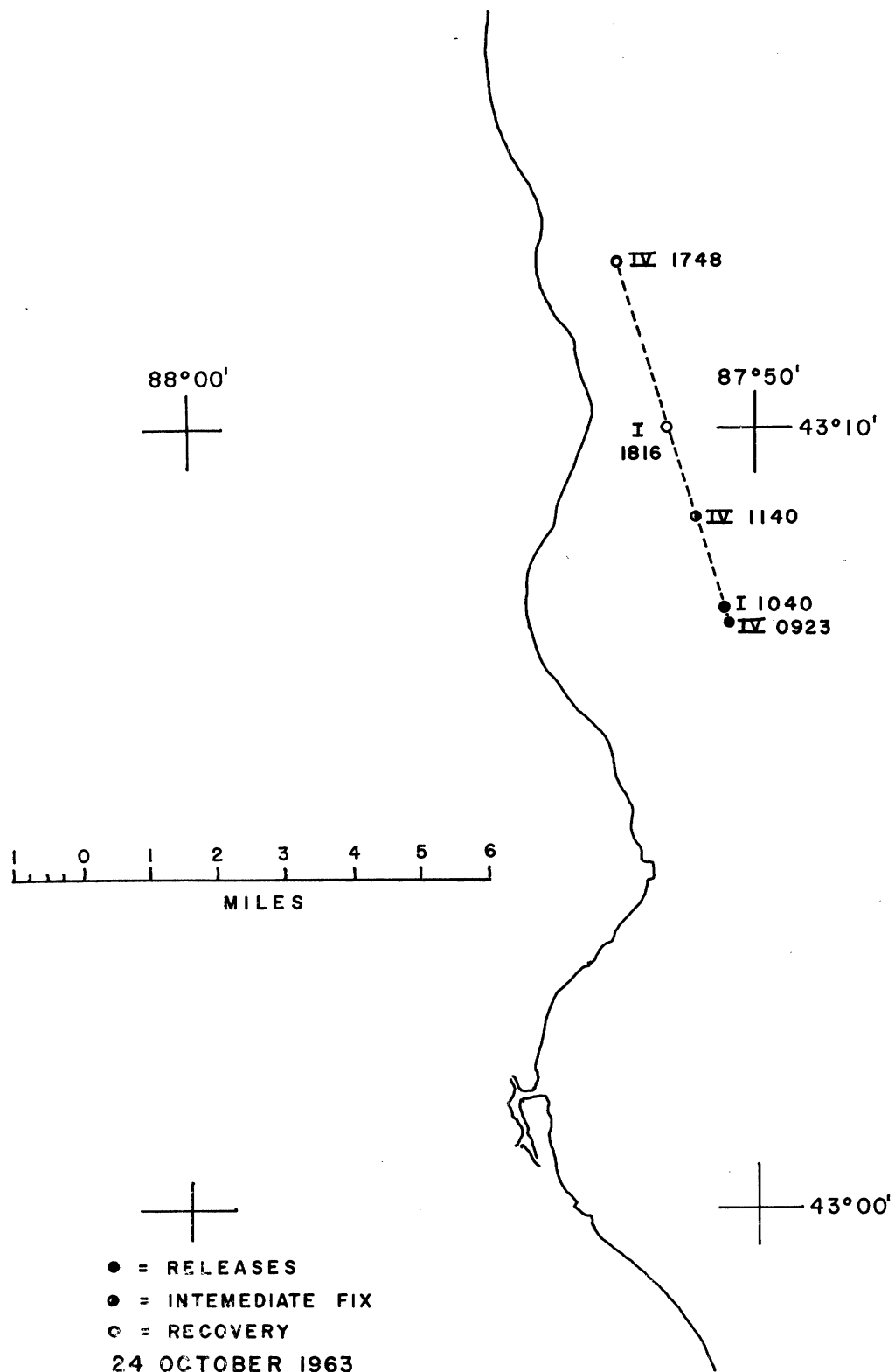


Figure 11

The wind regime related to this run was:

23 Oct. S 12 knots (diminishing during night)
24 Oct. S 9-12 k (18 k later in the day)

Drogue run, 24-25 October 1963, near USPHS Buoy 18 (Fig. 12):

On 24 October surface drogue V was set at 1253 about halfway between USPHS buoys 17 and 18, and surface drogue III at Buoy 18 at 1400. The drogues were recovered on 25 October. During this run positions were obtained by a combination of dead reckoning and radar range and bearings on Buoy 18.

Drogue V drifted an apparent 5.4 miles during the 23 hours 37 minutes it was adrift, to give an indicated surface current velocity of 0.23 mph. Drogue III moved 4.8 miles in 21 hours 27 minutes, an indicated velocity of 0.22 mph.

The time-series of positions during this run was:

24 Oct. 1253 #V 43°07.9', 87°36.2' (set)
1400 #III 43°08.0', 87°24.4' (set, at Buoy 18)
25 Oct. 1127 #III 43°11.3', 87°21.0' (recovery)
1230 #V 43°09.5', 87°30.1' (recovery)

The wind regime applicable to this run was:

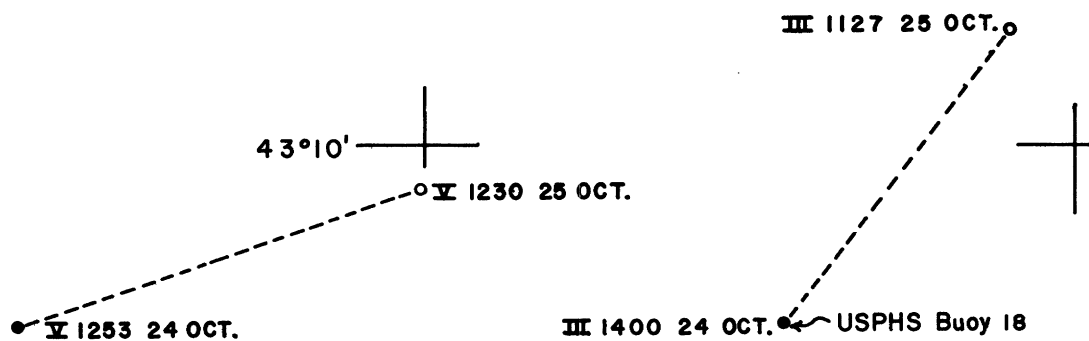
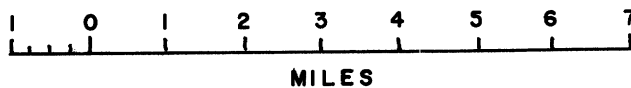
23 Oct. S 12 knots (diminishing during night)
24 Oct. S 9-18 k
25 Oct. SSW 8-12 k

Studies off Grand Haven and Muskegon

Drogue run, 24-25 June 1963 (Fig. 13): This run was designed to be a further test of the radio-drogue as well as a test of the relative directions of deep and surface currents off Grand Haven. Fresh batteries had not been put in the transmitters, with the result that the transmitters ran down. Fortunately, a blind radio-call to the entire east side of the

87°30'
43°20'

87°20'



● = RELEASES ON 24 OCTOBER 1963

○ = RECOVERIES ON 25 OCTOBER 1963

Figure 12

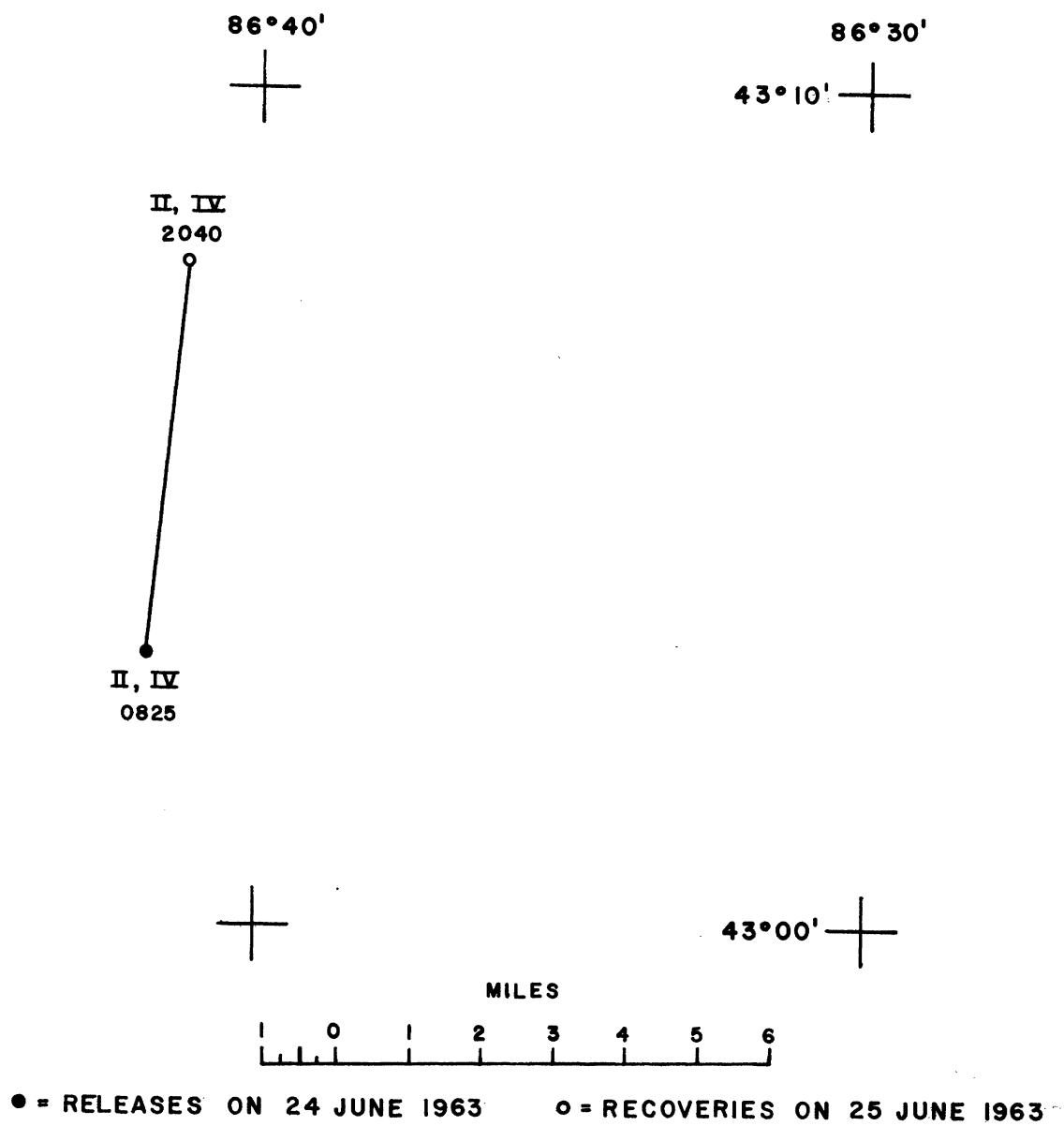


Figure 13

lake elicited the information that the MILWAUKEE CLIPPER had seen the drogues; from her directions we were able to recover them. Positions were by radar fix.

Drogues II (surface) and IV (125 feet) were set at $43^{\circ}03.3'$, $86^{\circ}41.8'$, 22.3 miles west of Grand Haven at 0825 on 24 June. On 25 June the two, still together, were recovered at 2040 at $43^{\circ}07.9'$, $86^{\circ}41.2'$ 18 miles 252° true from Muskegon. There was no separation of these drogues during their 36 hours 15 minutes adrift. They had travelled an apparent 5.4 miles, giving an indicated current speed at both depths of 0.15 mph.

The wind regime for this run was:

24 June	SSE	4-8 knots
25 June	SE	6-8 k (going calm in afternoon)

Drogue run, 27-28 October 1963, at USPHS Buoy 20 and Weather Tower (Fig. 14): On 27 October surface drogue I was set alongside the USWB-USLS-USPHS-UM weather tower off Mona Lake inlet at 0934. Deep drogue II (130 feet) and surface drogue III were set beside USPHS Buoy 20 at 1059 and 1104 respectively. Recovery positions of II and III were by timed run to Buoy 20; positioning of I was by sextant fix.

Drogue II was recovered at 1350 after moving 0.34 mile toward 098° true--an indicated speed of 0.12 mph. Drogue III was retrieved at 1355 after moving 0.58 mile toward 074° true at an indicated speed of 0.20 mph.

Drogue I was positioned at 1640 at a point 1.6 miles 164° true from the tower, having moved at an indicated speed of 0.23 mph. This drogue was left adrift overnight and was

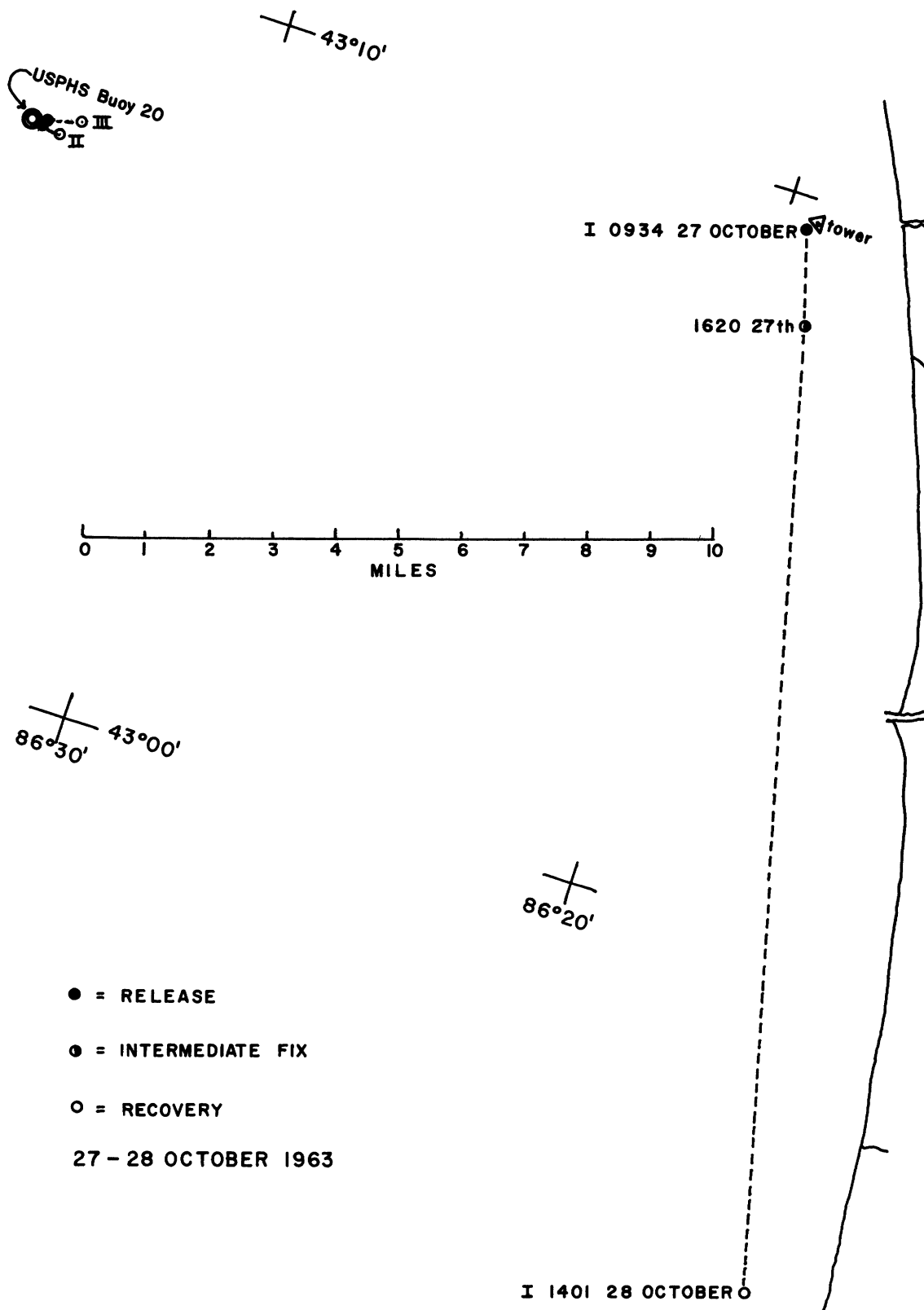


Figure 14

recovered on 28 October at 1401 at $42^{\circ}55.3'$, $86^{\circ}14.5'$, about two miles 317° true from the channel at Port Sheldon. From release to recovery this drogue moved 16.8 miles in 28 hours 27 minutes for an overall indicated speed of 0.59 mph. Between the intermediate and final positions this drogue moved 15.2 miles at an indicated rate of 0.7 mph.

The regime of winds applicable to this run was:

26 Oct.	SSW	8-12 knots
27 Oct.	S	8-13 k
28 Oct.	NW	18-23 k

BT and drogue run, 29 October 1963, at USPHS Buoy 20 (Fig. 15): This section presents a comparison of currents obtained by dynamic computation to currents indicated by surface drogues. The drogue run has been reported previously in Part I of this Final Report.

To enable comparison to the computed currents, the normal components of the movements of adjacent drogues have been averaged and the average plotted between the drogue positions.

The comparison is hampered by the fact that higher-windage floats had to be used on half the drogues. The averaging process included a higher-windage drogue in each pair. The comparison would have been further facilitated if the bathythermograph soundings had been in between the drogues. Each computed current component would then have been directly comparable to the normal component of the movement of a single drogue.

While the mechanics of the comparisons leave a good deal to be desired, there was at least directional agreement in five of the nine comparisons. In three of the four remaining

MILES FROM SHORE

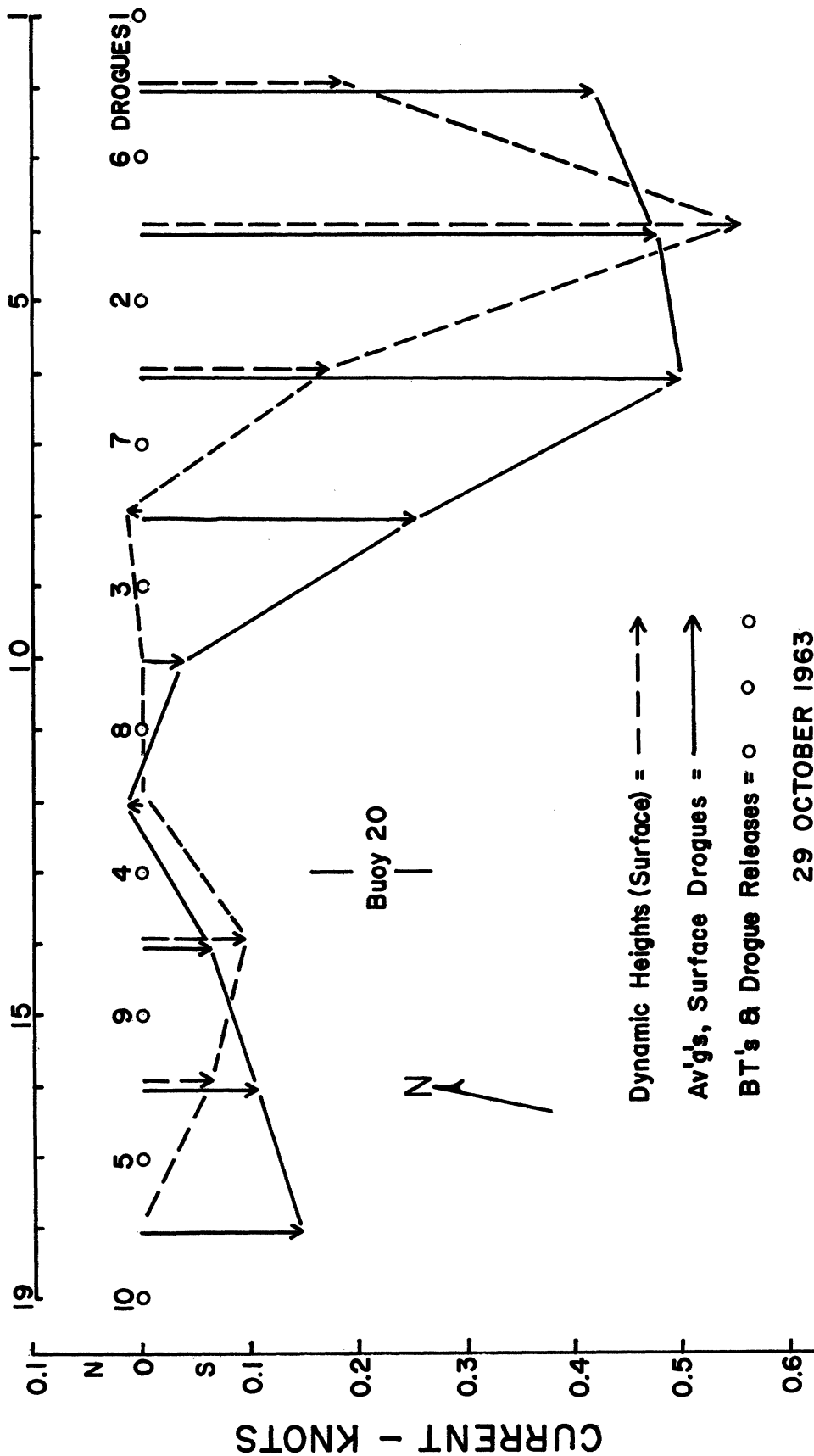


Figure 15

comparisons movements of drogues were paired with no-current indicated by dynamic heights. In only one of the nine was there direct disagreement in direction between the computed current and that indicated by drogue. In five of the nine comparisons current velocity indicated by the two methods was in order-of-magnitude agreement.

The comparison was carried out under north winds of 10-18 knots which began during the early forenoon and continued through the day. Winds of the 28th had been northwest 18-23 knots.

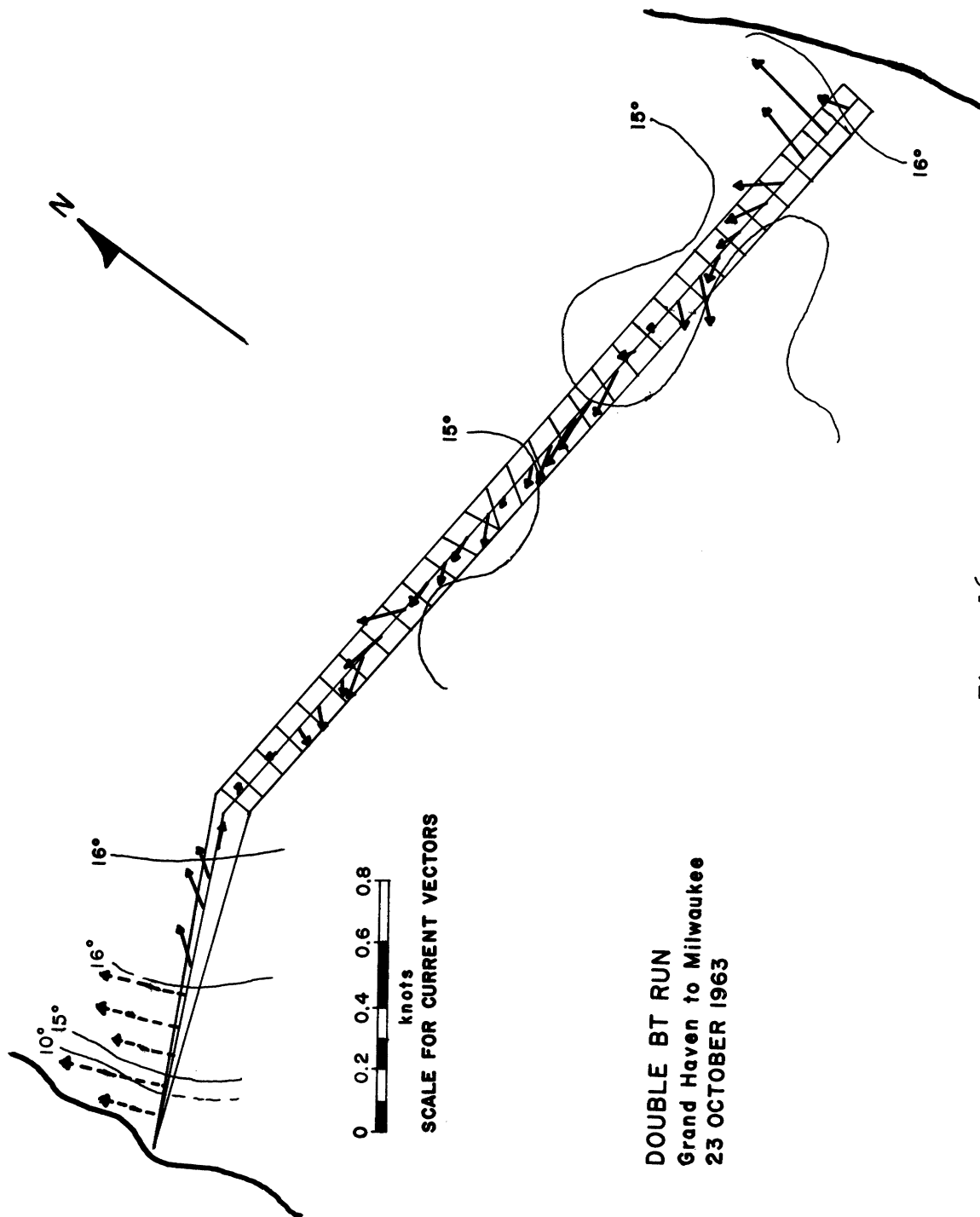
Double BT Run, Grand Haven to Milwaukee (Fig. 16)

On 23 October 1963 the vessels INLAND SEAS and MYSTIC carried out what was supposed to be a parallel run of bathythermograph soundings between Grand Haven and Milwaukee.

Inexperience with such runs is credited with the boats' steering north of the course, and then converging after course-correction. Corrective measures have been taken.

Figure 16 presents the results of this run. The two outer lines represent the paths of the two ships. Cross-lines intersect the two ships' courses at the points where BT soundings were taken. The center line connects the middle-points of the "squares" which have BT soundings on each corner.

Current directions and velocities have been determined by application of the dynamic height method: 1) along the track of each ship, and 2) transversely to the ships' tracks along the short cross-lines. Components of current: 1) normal to the ships' tracks, and 2) parallel to the ships' tracks were thus



DOUBLE BT RUN
Grand Haven to Milwaukee
23 OCTOBER 1963

Figure 16

obtained. Mean components were computed from the mean slopes of the surface; slopes along the ships' tracks being averaged and slopes transverse to the tracks being averaged. The two components thus obtained for each "square" were summed vectorially to produce the current vector that is drawn from the midpoint of each "square."

Isotherms of 15° and 16°C are entered in the figure in the places where they were encountered by the two ships.

In the last ten miles of the short converging leg of the crossing, only the current components normal to the ships' tracks were computed. The averages of these are shown as dashed arrows.

The wind regime under which these crossings were made was:

22 Oct.	S	20-25 knots
23 Oct.	S	12 k (diminishing during night)

Although the 2-mile spacing between the ships' tracks is too small to delineate clearly the nature of the current structure, it is sufficient to suggest that eddies of different sizes and of both right-hand and left-hand rotation were present and probably moving within an overall drift. Single transects across such a structure would produce the appearance of "streaks" of oppositely directed current as reported in Part I.

Tests of Windage Effects on Drogues

Test of 9-10 October 1963 (Old Floats, Old Drags): The old-style drogue floats consisted of a styrafoam float 16-1/2 inches square and six inches deep. Through the center of the styrafoam there was a 10-foot aluminum pipe of 5/8th inch

outside diameter. This pipe (staff) extended 6-1/2 feet above the top of the styrafoam and three feet below it. The lower end of the aluminum staff was weighted with three one-pound iron fish-net sinkers, and four guy-wires ran from the bottom of the staff through the corners of the styrafoam to 15 inches from the top of the staff. At the top of the staff was mounted a wire-mesh radar corner reflector measuring one foot in each dimension.

In the usual use these floats exposed to the wind the radar reflector, the upper portion of the staff, the guy wires, a rope bridle for recovery, and one side of the styrafoam float (16-1/2 x 4 inches exposed). Total area exposed to the effects of wind was 270 square inches.

Figure 5 presents the details of this test. Drogues III and IV were normal surface drogues; each carried at the lower end of its staff a 4-foot x 8-foot sheet of galvanized iron rolled and bolted into an open-ended cylinder and suspended by a light chain bridle. These drogues were influenced by the upper 7-1/2 feet of water. Drogue II carried two current drags (cylinders) in tandem and was effected by the upper 12 feet of water. The tandem drag configuration was used on the assumption that windage on the float would not be able to tow it to any significant degree.

As shown in Figure 5, drogues II, III, and IV retained about the same relative positions to each other from the "noon" fixes of the 9th until recovery on the morning of the 10th.

Drogue II travelled 6.7 miles during its total period adrift; this gives an apparent mean speed of 0.29 mph. Drogues

III and IV both moved at apparent mean speeds of 0.34 mph. If the difference in indicated speeds is taken to be the result of windage on the drogue float, then the windage errors are 0.05/0.29 or 17.5%.

Test of 26 October 1963 (Old Floats, Old Drags): In this test drogue II again carried two current drags in tandem and was compared to drogue III, a surface drogue.

Drogue II travelled at an indicated speed of 0.43 mph; drogue III moved at an indicated speed of 0.52 mph.

Again taking the difference in indicated speeds as a measure of the towing effect of wind pressure on the drogue float, we have 0.09/0.43 or 20.9% windage error.

NOTE

The indicated speeds of drogues that are given in the preceding sections have not been corrected in any way for windage error.

Supplemental Sediment Studies

Oily Sediments off Gary, Indiana

In May 1964 the areal extent of the oily sediments off Gary, Indiana, which were reported in Part II of this Final Report, was worked out in detail by R/V MYSIS.

Figure 17 gives the extent of these sediments. They occupy an area about four miles long by about 1-1/2 miles wide oriented in a northwest-southeast direction and lying to the east and south of Buoy R2 off Gary.

These sediments are primarily of oily silty sand. They do not show any continuation to the shore. The nature of these sediments is very similar to that of sediments collected from a known spoil-dumping area off Milwaukee at 42°59.5', 87°47.0'.

We now believe that the sediments off Gary are also spoil (dredgings) from harbor dredging operations along the southern end of the lake. As spoil, these sediments represent a man-made modification of the lake environment but not one that can be attributed to the eutrophication process in the sense in which that term is usually used.

Foul-Odored Sediments off Calumet Harbor

In May 1964, also, the MYSIS made a detailed search for the foul-odored sediments which had previously been found off Calumet Harbor, and which were reported in Part II.

No evidence of these foul-odored sediments was found. The condition that was present during the bottom survey reported in Part II was, then, a temporary condition for which no cause can be given.

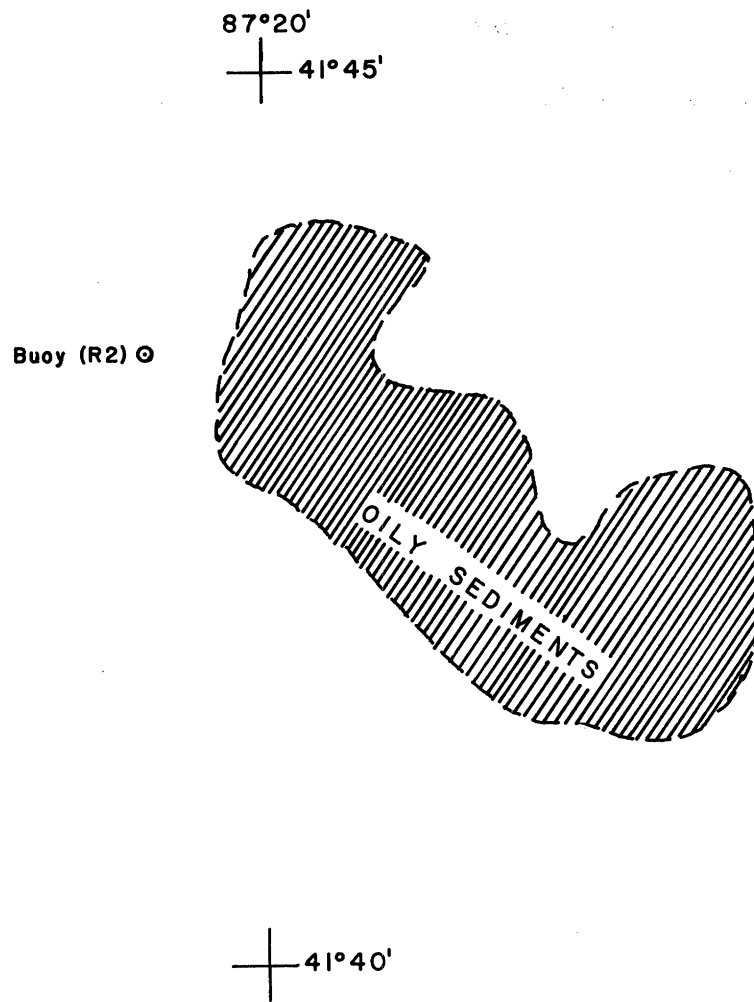


Figure 17

Milwaukee Embayment Survey

In June 1964 the R/V INLAND SEAS carried out a detailed sediment survey in the embayment on which the city of Milwaukee is located.

In no part of the embayment outside of the seawall was there any physical evidence of eutrophic modification of bottom sediments.

The effluent from the Milwaukee sewage disposal plant is dumped directly into Milwaukee harbor, inside the seawall, by an outfall at the east end of the disposal plant property. The sediments behind the seawall from North Entrance to South Entrance and Shore Park Breakwater Light (USLS Chart No. 743) are all black; all are heavily organic; and all appear rich in worms.

Behind the seawall the water is discolored and turbid. Its uncorrected conductivity values run 30 to 50 percent higher than those of water outside the seawall. Water in the vicinity of the outfall is nearly black and smells of hydrogen sulphide. Streams of discolored high-conductivity water blow downwind out through the openings in the seawall and can be traced visually for considerable distances into the open lake.

Limitations of draft prevented the INLAND SEAS from exploring the sediments and water behind the seawall south of Shore Park Breakwater Light.

CONCLUSIONS

Local currents in the shallow waters off Chicago appear to move essentially in downwind directions. This was also true for the one run of drogues at USPHS Buoy 14 in midlake off Racine, for the one run near the position of USPHS Buoy 17, and for two runs off Grand Haven.

Local currents between USPHS Buoys 17 and 18 and at USPHS Buoy 18 (only one run each) appeared to contain direction components transverse to the wind direction.

Local currents at USPHS Buoy 20 usually were not directed downwind. It is believed that set-up and other effects of shore and nearby sloping bottom were in part responsible.

The annual regimen of temperature (density) in the waters off Chicago indicates that a typical two-layered water column is not apt to occur there. In the absence of temporary two-layered conditions caused by internal wave activity, surface and bottom currents off Chicago may be expected to move in more or less the same directions.

The general tendency for downwind movement of currents off Chicago, and one case of observed westward current under onshore wind, are taken to indicate that effluents from the proposed diffuser would be able to reach the intakes and beaches of Chicago under onshore winds.

Crude estimates of apparent dilution in the waters off Chicago indicate that the region is one of poor inherent ability to dilute introduced materials.

Definite eutrophic change in the nature of bottom sediments

exists in Milwaukee harbor where sewage effluent is discharged behind the seawall. Except in harbors, there now appears to be no place in lower Lake Michigan where typical eutrophic modification of bottom sediments is taking place.

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